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The current approach for CCTT (Close Combat Tactical Trainer) scheduling considers only one resource constraint, semi-automated computer generated forces (SAF). Use of this approach can result in an infeasible schedule being produced because it only considers total SAF and the resulting schedule often exceeds the capacity for manned simulator modules as well as other limited resources.

In selecting scenarios for training, units may choose from several alternatives, all of which may support a desired set of training objectives. It is assumed that the objective of the schedule, maximizing resource utilization, would be highly desired by military leaders and managers of the CCTT system. Therefore, a "greedy" heuristic approach is used to solve the multi-stage scheduling decision process. The problem was formulated using a zero-one integer program where the algorithm minimizes slack resources at each stage of the scheduling process subject to local and temporal constraints. Stage times are defined as scenario completion times. By minimizing slack resources, resource utilization is maximized.

Results generated by the algorithm developed in this thesis were both feasible and efficient. In all cases, resource constraints and all precedence relationships were satisfied. Key resources (simulators and SAF workstations) had utilization percentages ranging from 69% to 92%.

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A DYNAMIC GREEDY HEURISTIC FOR SCHEDULING TRAINING SCENARIOS

by

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B.A. Wofford College, 1987

A thesis submitted in partial fulfillment of the requirements
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ABSTRACT

The ability of US Army to ensure efffective and efficient use of training resources is of paramount importance during a time of shrinking budgets. A high tech training device currently being tested for fielding is the Close Combat Tactical Trainer (CCTT). It combines virtual and constructive simulations and manned simulator modules to replicate battlefield conditions for the training battalion and smaller combat units. Because of its significant per unit cost, each CCTT site costing in excess of $20 million, effective scheduling of training scenarios for multiple users is required.

The current approach for CCTT scheduling considers only one resource constraint, semi-automated computer generated forces (SAF). Use of this approach can result in an infeasible schedule being produced because it only considers total SAF and the resulting schedule often exceeds the capacity for manned simulator modules as well as other limited resources.

In selecting scenarios for training, units may choose from several alternatives, all of which may support a desired set of training objectives. When all scenarios from a given list are not required to be scheduled, the traditional project scheduling network approach cannot be used

It is assumed that the objective of the schedule, maximizing resource utilization, would be highly desired by military leaders and managers of the CCTT system. Therefore, a "greedy" heuristic approach is used to solve the multi-stage scheduling decision process. The problem was formulated using a zero-one integer program where the algorithm minimizes slack resources at each stage of the scheduling process subject to local and temporal constraints. Stage times are defined as scenario completion times. By minimizing slack resources, resource utilization is maximized.

Results generated by the algorithm developed in this thesis were both feasible and efficient. In all cases, resource constraints, individual and group precedence relationships, and simultaneous scenario scheduling requirements were satisfied. CCTT schedules remained feasible from start to end. Resource utilization percentages were considered "acceptable" by sources familiar with the CCTT system. Key resources such as M1 Tank simulators, M2 Bradley simulators, SAF workstations, and after action review stations (AAR) had utilization percentages ranging from 69% to 92%. The scheduling heuristic performs well for all constrained cases and produces results comparable to the hybrid expert system when SAF only constraints are used.

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CHAPTER 1

INTRODUCTION

The "fall" of the Berlin Wall in 1989 has symbolized the end of the Cold War between the United States and the former Soviet Union for many people. Its impact has been felt world wide, especially in terms of United States (US) military force structuring and modernization. Of particular importance has been the modifications in US Army training and doctrine resulting from the changes in foreign policy and global military force projection. Once a large, highly mechanized, forward-deployed army capable of defending against a Soviet assault across the fields of central Europe, the US Army now trains more as a force projection power capable of deploying from military bases world wide to crisis situations anywhere on the globe on very short notice. These changes in national military strategy have resulted in significant force reductions and defense budget cuts both in the US and abroad. As a result, the Army has been forced to develop new and creative ways of training efficiently and effectively while simultaneously satisfying budget requirements.

A family of "cutting edge" technology computer-based training simulators called *Combined Arms Tactical Trainers (CATT)* are being developed to meet these criteria.

These simulators will allow US soldiers to train for battle on a "virtual battlefield" that provides all the sights, sounds, and realism of actual training maneuvers at a fraction of the cost. Among the first of the CATT family to be fielded is the *Close Combat Tactical Trainer (CCTT)* (TRADOC, 1994).

CCTT allows for training platoon, company, and battalion sized armored and mechanized units at fixed or mobile training sites. A distributed interactive simulation network within CCTT connects manned modules and virtual and constructive simulations to create the virtual battlefield. The proposed CCTT training site configuration will include manned simulator modules, operations center workstations, semi-automated forces (SAF) workstations, and after action review (AAR) stations (STRICOM, 1991, and US Naval Training Systems Center, 1992). Figure 1 shows the fixed site layout and system diagram.

Manned modules may include various combinations of *M1A1/A2 Tank* simulators, *M2/M3A2 Bradley* simulators, *Dismounted Infantry (DIM)* simulator modules, *High Mobility Multi-purpose Wheeled Vehicle (HMMWV)* simulators, *Fire Support Team Vehicle (FIST-V)* simulators and *Armored Personnel Carrier (APC)* simulators. Each simulator is designed to replicate the dimensions, configuration, and warfighting capabilities of an actual tactical vehicle or fire team (DIM). Soldiers operating the simulators (manned modules) are immersed in a virtual world where radio transmissions, enemy detections and friendly responses are almost as real as those on the actual battlefield.

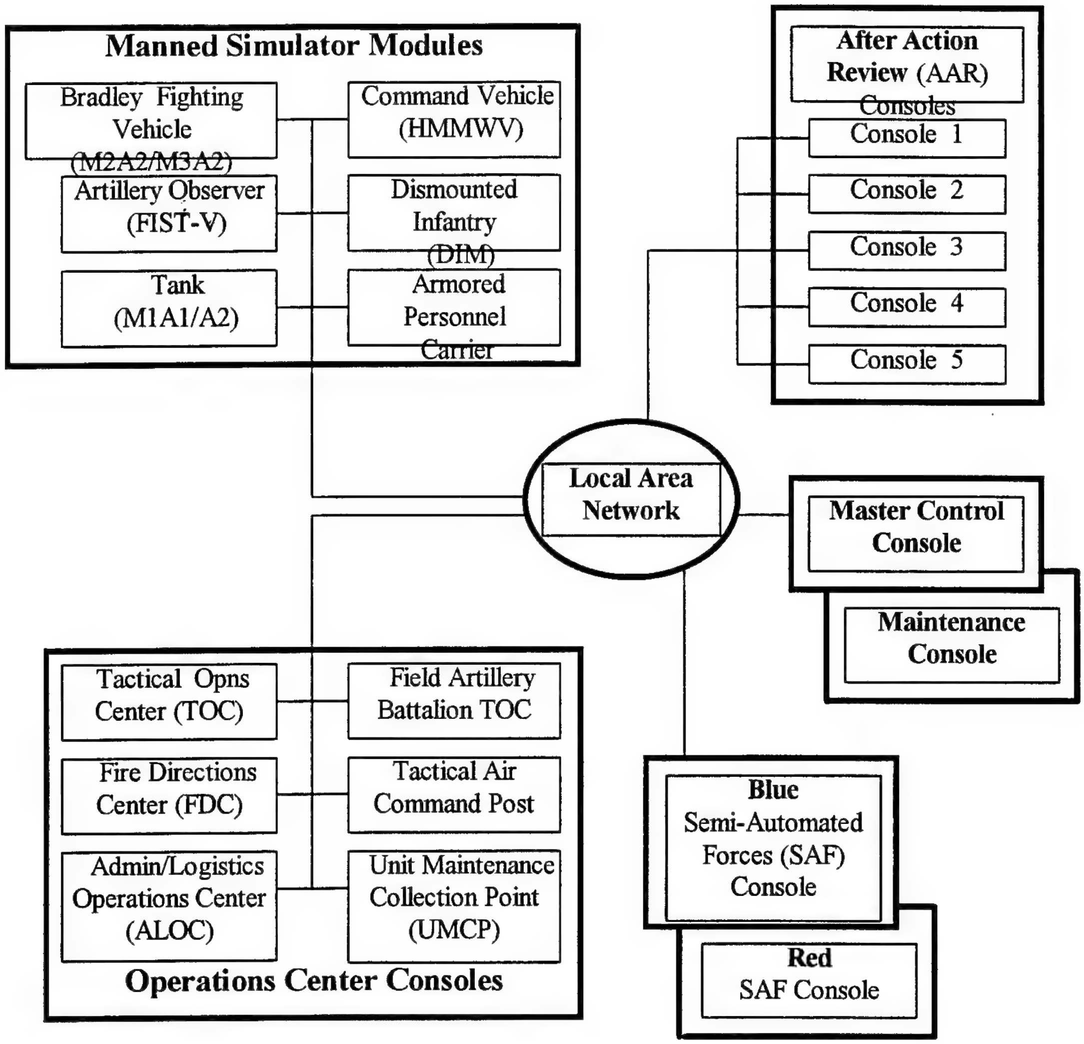


Figure 1. Fixed site Close Combat Tactical Trainer layout and system diagram.

The operations center consoles may include various combat support components of a *Battalion Tactical Operations Center (TOC)*. These stations are manned primarily by soldiers from logistical support Military Occupational Specialties (MOS) such as quartermaster (supply, maintenance) and ordnance (weapons, munitions). Their purpose is to provide the necessary battlefield logistics for the simulated combat exercise.

The SAF work stations include both "friendly" forces (BLUESAF) and "enemy" forces (REDSAF). SAF operators are usually government-contracted civilians who operate these *computer generated forces (CGF)*. BLUESAF are normally used as augmentation for a training unit allowing it to train within a larger unit context. BLUESAF are also used to provide some necessary combat support such as Engineers and service support operations such as maintenance and logistics. For example, a platoon of soldiers in the manned modules may operate as part of company exercise where the other two platoons necessary for a company element are computer generated forces controlled by the BLUESAF operator.

After action review (AAR) stations are used by unit leaders (who are the trainers) to review and critique completed training exercises (scenarios). Generally, lessons learned from exercises are derived from the AAR. The station consists of US Army communications equipment and an advanced computer system with several computer monitors to allow for complete exercise analysis. The system is capable of replaying scenes and "zooming" in or out to specific locations or vehicles.

Training exercises (scenarios) must be selected by the unit for scheduling at the CCTT site. First, a training needs identification process takes place at the unit level where commanders subjectively rate their unit's training proficiency in specific wartime tasks. Critical warfighting tasks are included in the unit's *Mission Essential Task List (METL)*, a list of tasks that are considered essential for the unit to perform its war time mission. Based on this list of tasks (training objectives), the CCTT facility generates a

list of training scenarios from the *Standard Army Training System-Training Exercise Development System (SATS-TREDS)* library which will best support the tasks (training objectives) identified by the unit. There may be several scenarios that support a given set of training objectives. This list of training scenarios is then forwarded to the unit for consideration and selection. The unit evaluates the scenarios and may select, modify, eliminate, or create the scenario(s) of their choice. Once the unit has selected the training scenarios that support their training needs, the list is sent back to the CCTT facility for scheduling.

Various resource combinations are required for each training scenario depending on the following factors:

(a) <u>the type of unit training</u> - armored, mechanized infantry, light infantry, or calvary troop,

(b) <u>the size of the unit training</u> - platoon, company, or battalion,

(c) <u>the context of the unit training</u> - platoon fighting as a platoon, platoon fighting as part of a company (requires additional BLUESAF), company fighting as a company, company fighting as part of a battalion (requires additional BLUESAF), or battalion fighting as a battalion (insufficient manned modules require the use of BLUESAF),

(d) <u>the general category of mission</u> - conducting a movement to contact (MTC), conducting an attack, or conducting a defend in sector mission,

(e) unit's training proficiency - trained (T), partially trained (P) requiring further practice, or untrained (U), and

(f) size of opposing force - squad, platoon, company, battalion, or regiment (REDSAF requirements). A unit may train against one of three opposing force echelons (i. e., a unit training as a platoon may be opposed by either a squad, platoon, or company).

Each combination of the six factors identifies a single possible training scenario category and there may be numerous scenarios per training category. Potentially, there may be thousands of training scenarios in the *SATS-TREDS* library, each with a unique exercise length (duration) and differing resource requirement. The scenario selection problem is beyond the scope of this research. It is assumed that scenarios have been selected and that their corresponding resource types, resource quantities, scenario durations, and precedence relationships (if any) have been identified to the CCTT schedule manager. In general, units may select several scenarios to achieve a particular training objective where only a subset of these training scenarios will be scheduled.

CCTT was designed to be a high fidelity training enhancer. However,the significant per unit cost of the system means it will be limited to fielding in relatively low quantities at selected sites. Consequently, demand for its use will probably be high. The need for efficient scheduling of the CCTT site becomes extremely important because of the various active Army, Army Reserve, and National Guard units requiring its use. Site managers can no longer rely upon the "trial and error" methods often used on

military installations for scheduling traditional training resources such as weapon ranges and training areas. The size and complexity of this resource constrained scheduling problem requires a systematic and efficient way of scheduling simultaneous multiple scenarios, each requiring multiple resources and having various durations, throughout the planning horizon. CCTT managers may desire to maximize the utilization of the available resources.

1.1 Problem Identification

1.1.1 Problem Statement

Given a set of scenarios, their resource requirements, their exercise durations, and their precedence relationships, how can the CCTT site manager effectively schedule these training scenarios over the planning horizon? The planning horizon can range from a single day to six months or more. In this thesis, it is assumed the planning horizon is one day. Because the current approach developed by McGinnis and Phelan (1996) to generate a CCTT schedule is not guaranteed to produce a feasible schedule since it considers only RED SAF and *no other* resource limitations when generating a schedule, another approach is required that guarantees a feasible schedule with respect to all resource limitations.

1.1.2 Scope

Training is assumed to be continuous throughout the planning horizon. A scenario may start as soon as another one is completed provided sufficient resources are available for the new scenario. CCTT allows for up to five different exercises to be conducted simultaneously provided adequate resources are available. This proposed solution is based on a multi-stage decision process structure and uses a zero-one integer program to minimize slack resources at each stage of the scheduling process. By minimizing unused resources at each stage, resource utilization is being maximized at each stage. By maximizing resources at each *stage* of the planning horizon and not necessarily maximizing resource use over the *entire* planning horizon, we are using a *greedy* heuristic formulation approach to obtain a "good" (and feasible) CCTT schedule.

Resource constraints include all manned simulator modules, AAR stations, and SAF workstations at the CCTT site. According to experts familiar with CCTT structures, operations center workstations are not considered a resource constraint since they will be available for use by units undergoing training or these capabilities will be simulated as BLUESAF.

1.2 Background Information

McGinnis and Phelan (1996) recently developed a hybrid expert system in their attempt to solve the CCTT scheduling problem. Their solution approach was based primarily on the current estimated SAF *entity* processing capability of the CCTT

computer system, approximately 600 entities. The allowable SAF entities per SAF workstation, simulator modules, and AAR stations were not considered. McGinnis and Phelan's approach is discussed in detail in Chapter 2.

Each SAF workstation operator can control up to approximately 60 SAF entities. An entity is basically any system component that can be seen and/or manipulated on the virtual battlefield such as vehicles, soldiers or missiles. Although entities may look and act the same for both the enemy and friendly forces, they cannot be mixed at a single SAF workstation and therefore cannot be treated as "like" resources. BLUESAF and REDSAF in a single unit scenario (exercise) must be operated at separate workstations even if their combined entity total is less than sixty. For example, 40 REDSAF and 15 BLUESAF in a single scenario require two SAF workstations. A total of ten SAF workstations are allocated per CCTT system which means that the system can accommodate up to 600 SAF entities *if they decompose into groups of 60 like entities per group*. Generating a CCTT training schedule based only on this "total SAF available" criterion does not necessarily generate a feasible schedule considering other resource requirements. Ignoring the other resource constraints further increases the likelihood that the schedule generated using this approach is infeasible.

1.3 Research Objectives

The objective of this research is to develop a viable tool for scheduling CCTT training scenarios that allows the user to input all available resource parameters and

scenario selections and obtain a schedule that is both feasible and efficient (Figure 2). Further, this work may provide the basis for extended research such as consideration of the impact of additional resources being added to the CCTT system, additional simultaneous exercise capability, and longer planning horizons. Chapter 6 discusses areas of further research and extensions.

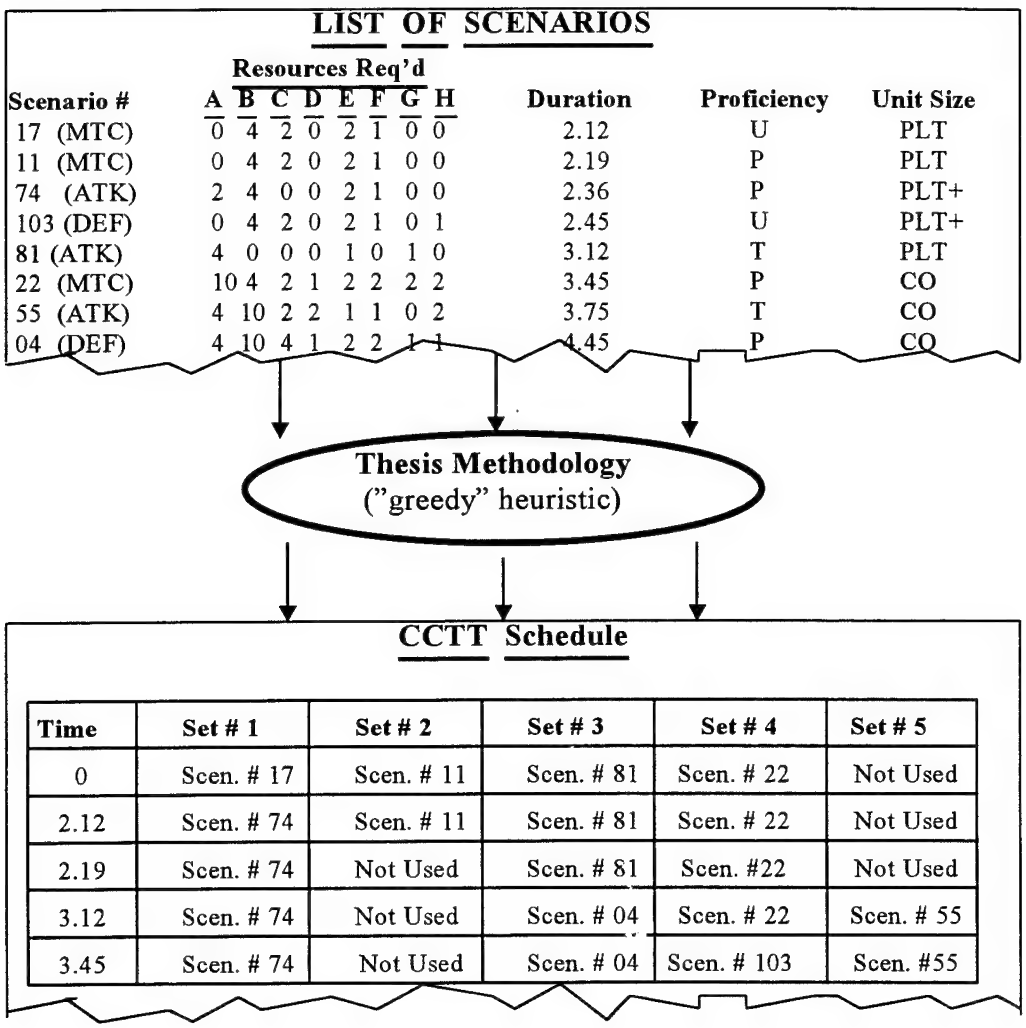


Figure 2. Overview of research objectives.

1.4 Assumptions

The following assumptions are made for problem formulation:

(a) duration of scenarios vary depending upon specific combinations of factors (unit proficiency, type, size, context, etc.) and are known ahead of time at the CCTT site,

(b) *After Action Reviews (AARs)* are required at the conclusion of a scheduled training event and are included in the exercise duration,

(c) administrative setup times are included in the exercise duration,

(d) scheduling priorities (when required) for unit training proficiency are *untrained (U)* units first, *partially trained (P)* units second, and *trained (T)* units third,

(e) scheduling priorities (when required) for unit training size are platoon (PLT) first, company (CO) second, battalion (BN) third, and

(f) battalion training scenarios exclude all other simultaneous scenarios, that is, no other unit may train simultaneously with the battalion, and it will be scheduled last during the planning horizon. This is consistent with the crawl, walk, run philosophy used in Army training

1.5 Definition of Terms

Armored Personnel Carriers (APC) simulators are simulators designed to give the user the perception that he is actually manipulating or operating an M113A3 (APC). The APC is a tracked vehicle used primarily for providing armored transport for soldiers or battalion staff officers.

Constructive simulation is a simulation with a game component that involves human interaction and computer models for replicating realistic scenarios.

Dismounted Infantry Module (DIM) is a four position workstation-like simulator with a sophisticated "joystick" and visual display system that allows infantry platoon leaders and squad leaders to simulate dismounted infantry individual soldier actions on the battlefield. The operator can manipulate the joystick to "see" the battlefield and maneuver the "virtual soldiers" as they walk/run/shoot on the "virtual terrain."

Distributed Interactive Simulation (DIS) is a time and space coherent representation of a virtual battlefield environment, measured in terms of the human perception and the behaviors of warfighters and/or with computer generated forces. DIS provides a structure by which independently developed systems may interact with each other in a well managed and validated combat simulation environment during all phases of the development process and in subsequent training (Piplani, Mercer, and Roop, 1994).

Fire Support Team Vehicle (FIST-V) simulator is a simulator designed to give the soldier the perception that he is actually manipulating or operating a FIST-V. The

FIST-V is the forward deployed artillery tracked vehicle that is responsible for spotting and controlling indirect fires.

High Mobility Multi-purpose Wheeled Vehicle (HMMWV) simulator is a simulator designed to give the soldier the perception that he or she is actually manipulating or operating a HMMWV. The HMMWV is a tactical wheeled vehicle that serves as a 1 1/4 ton cargo transport, light weapons platform, or scout reconnaissance vehicle. It is the modern version of the Jeep.

M1A1/A2 Tank simulator is a simulator designed to give the soldier the perception that he is actually manipulating or operating an M1A1 or M1A2 Abrams main battle tank.

M2/3A2 Bradley simulator is a simulator designed to give the soldier the perception that he is actually manipulating or operating a Bradley Infantry Fighting Vehicle (IFV) or Cavalry Fighting Vehicle (CFV). Bradleys are the primary weapons platform of the mechanized infantry.

Scenario is a situational combat exercise designed to train or test a unit's ability to perform its wartime mission. Examples of scenario types include movement-to-contact, attack, or defend. Scenarios differ in level of complexity/difficulty based on the size and type of the unit training. Scenarios in this thesis refer to computer generated (simulated) exercises. Scenarios have definite start and end times. The difference between the start and end times is the scenario duration.

Semi-automated forces (SAF)/Computer generated forces (CGF) is a collection of unmanned battlefield entities generated by a computer workstation and controlled by the workstation operator. CGF/SAF replace or supplement friendly, enemy or neutral manned simulators during a specific session (Piplani, Mercer, and Roop, 1994). SAF/CGF entities may be a single soldier, a single vehicle, or group of soldiers or vehicles. When grouped, the entities are commonly referred to as aggregate forces.

Simulators are computer mock-ups of vehicles or other objects physically occupied by humans.

Virtual simulations are simulations that occur in a virtual reality environment (also referred to as artificial or synthetic reality). Virtual reality perceives a participant's actions in terms of the body's relationship to a graphic world and generates responses that maintain the illusion that his actions are taking place within that world (Krueger, 1990). Another definition of virtual simulation used is the application of integrated technologies to enable a participant to perceive that he or she is occupying, to some degree, an environment other than that which he or she physically occupies (Loftin, 1993).

Workstations are modular panels usually consisting of a high speed advanced computer processing unit, one or more computer monitors for graphical battle displays, communications equipment for interaction with manned simulators, and controlled by civilian or military operators.

1.6 Outline of Thesis Research

Following this introductory chapter, the remainder of this thesis is organized into five chapters. Chapter 2 provides literature reviews of how this thesis relates to the resource-constrained project scheduling problems (RCPSPs). It also identifies approaches used for formulating and solving similar scheduling problems in both military and non-military applications. Chapter 3 outlines the development of the thesis methodology (Training Scenario Scheduling Problem (TSSP) scheduling heuristic) including mathematical notation, set definitions, objective function, resource constraint and state transition equations. A detailed account of how the algorithm was implemented in *Microsoft Excel®* is given in Chapter 4, Model Implementation. Chapter 4 also introduces the scenario types used to test the TSSP algorithm and the corresponding resource requirements for each scenario. Chapter 5 evaluates the results of the applied methodology to this set of scenarios, particularly in terms of resource utilization. The final chapter, Chapter 6, concludes the thesis by discussing the contributions of this research, the algorithm's limitations, and areas for future research and development.

CHAPTER 2

LITERATURE REVIEW

2.1 Resource Constrained Project Scheduling

Scheduling of training scenarios is really a matter of scheduling *activities* that "consume" resources and have precedence relationships. Therefore, algorithms that "solve" the RCPSP should be considered as possible approaches. A RCPSP consists of a set of activities coordinated by technological precedence relationships in which the allocation of scarce resources among competing activities must be considered in optimizing a specific objective function (Özdamar and Ulusoy, 1995). RCPSPs may use several techniques for obtaining solutions (Demeulemeester and Herroelen, 1992). The general solution approaches include integer programming for the *whole* problem, branch and bound techniques, and heuristics. *Whole* problem integer programming is inefficient because scheduling conflicts must be reevaluated over all activities of the project each time a precedence relationship is established. The success of using a branch and bound algorithm depends on its branching technique, either breadth first or depth first, and the strength of its lower bound. Normally, it is considered insufficient for problems of practical size regardless of how efficient they are (Özdamar and Ulusoy, 1995). Most of

the heuristic approaches have used priority or dispatching rules. Priority rules look at *all* activities and assign numbers (weights) to them to indicate the order in which they will be scheduled.

RCPSPs are usually concerned with minimizing makespan (project duration), maximizing the net prevent value (NPV) of money, minimizing total or weighted tardiness/lateness/completion time of a project, or some combination of the three (multi-objective). Resource-constrained project scheduling problems are generalizations of job shop scheduling problems and are *NP-hard*, meaning they cannot be solved in polynomial time (Demeulemeester and Herroelen, 1992). Because of this, we need to use heuristics (rule based procedures for obtaining good solutions). Heuristics can be either *static* or *dynamic*. Static heuristics make priority decisions initially (once) for the whole problem and dynamic heuristics allow priorities to be adjusted at various stages of the problem. It is known that dynamic heuristics work better, because they evaluate resource conflicts locally using current temporal and resource constraints, but require some additional work to implement. With heuristics, there are two scheduling approaches. One is to generate the "best" possible schedule without considering constraints and then adjust the schedule to get feasible. This is known as a *repair* heuristic. The other approach generates a feasible schedule and then improves it. This is known as an *improvement* heuristic.

The principal criteria used for the RCPSP are minimizing makespan or maximizing the net present value of the project. As indicated in the problem description, CCTT project managers desire to maximize resource utilization. It is known that an optimal

solution to the RCPSP that minimizes makespan also maximizes resource utilization (Bedworth and Bailey, 1987). It is not known whether a heuristic that focuses on minimizing makespan will also provide a good solution for maximizing resource utilization.

In addition to priority rules, some heuristics consider other factors in making the scheduling decision (Bell and Han, 1991; Ulusoy and Özdamar, 1994). Rather than develop *a priori* priorities (that may depend on the problem structure), Ulusoy and Özdamar developed a local constraint based analysis (LCBA) approach. Specifically, LCBA applied local essential conditions that respect the current temporal and resource constraints at each scheduling decision point. This approach has been shown to compare very favorably with the best priority rule heuristics in a computational comparison (Ulusoy and Özdamar, 1994).

The optimal and heuristic approaches to the RCPSP above require that all activities be scheduled. For the CCTT problem of scheduling training scenarios, the training units may identify a set of training scenarios of which only a subset need be scheduled. This is a more general problem than the RCPSP. However, when all training scenarios must be scheduled, the above approach for the RCPSP may be viable methods for scheduling training scenarios.

2.2 Feasible Scheduling Heuristics

There have been several scheduling heuristics that have recently been applied to training related scheduling problems. The following approaches were applied to non-Army problems. Both approaches develop resource feasible schedules.

Busch and Mulvey (1996) developed a Quick Course of Action (QCOA) Toolkit which provided a scheduling and analysis tool to help the Air Mobility Command (AMC) accomplish their contingency planning mission. They used a linear programming formulation with four classes of variables to model the problem. A "preferred" class separates two of the aircraft configuration variables, one variable indicates the number of various aircraft types, and one class accounts for cargo shortfalls. This methodology does not attempt to find optimal solutions but attempts to provide "good" schedule and aircraft type *estimates*.

Sampson and Weiss (1995) used a similar heuristic approach applied in two steps to solve a conference scheduling problem. Phase one (*scheduling*) of their solution approach assigned conference sessions to nonoverlapping time periods and to available rooms with predetermined capacities. Phase two (*enrollment*) assigned conference participants to sessions based on their personal preferences. This was accomplished using a weighting factor. Other constraints were also considered such as instructor requirements for time slots, presentation equipment, and so forth. The objective of their work was to produce a feasible schedule that allowed maximum aggregate participant satisfaction and minimal session "hopping."

2.3 Related Army Scheduling Work

In 1987, Yang and Ignizio solved a training resource and training events scheduling problem (Yang and Ignizio, 1987). Their solution approach involved scheduling resources and events via heuristic methods implemented in two steps. The nature of the problem concerned scheduling a fixed number of US Army battalions at the same military installation with restrictions on resource types, quantities, and task order. These features of the problem occasionally required two or more battalions to work together and share resources in accomplishing some training tasks.

Considerable work has been done by McGinnis in the area of US Army resource constrained scheduling problems. McGinnis and Fernandez (1994a, 1994b) used dynamic programming to optimally schedule training resources for initial entry training, specifically, the US Army's Basic Combat Training (BCT) phase. The scheduling problem was to determine the number of recruits to assign to each of the hundreds of training companies nationwide in each week of a two year planning horizon. Simultaneously scheduling these companies at various US training installations across the country was accomplished by formulating a dynamic system model of Basic Combat Training. Further, McGinnis and Fernandez (1994a and 1994b) developed a three phase heuristic procedure implemented in a decision support system for efficiently solving real world problems. Performance measures included training quality (evaluated as instructor-to-trainee ratios), resource utilization, and training costs. In addition, their approach does not consider other resource requirements and the resulting schedule is likely to be infeasible and thus requiring one further repair heuristic to restore feasibility.

2.4 Related CCTT Scheduling Work

More recently, attempts at trying to solve the CCTT training scenario scheduling problem have been made. McGinnis and Phelan (1996) developed a hybrid expert sytem for scheduling CCTT training.

The mathematical formulation for this approach has two subproblems: (1) the training scenario scheduling problem and (2) the training resources scheduling problem. The objective of the first subproblem is to *maximize* training opportunity. This objective is accomplished by assuming a user-determined value $c_j\ (t)$ for each scenario which reflects the contribution of each scenario to the unit undergoing training. The goal is to maximize the sum of scenario values at each time period across all simultaneous scenarios during the planning horizon. The objective of the second subproblem is to *maximize* the use of training resources. By assuming that training quality is measured by maximizing REDSAF entities for each training scenario, this objective is accomplished by *minimizing* idle REDSAF for each time period across all simultaneous scenarios during the planning horizon. Their methodology generates a schedule by varying REDSAF entities between upper and lower bounds. The algorithm fixes the REDSAF at their respective lower bounds, generates a schedule, tests for feasibility, and makes necessary adjustments by substituting or deleting scenarios. If feasibilty is attained, the scenarios are then set at their REDSAF upper bounds (possibly becoming infeasible). Next, a heuristic policy improvement makes a series of forward and backward passes through the schedule

adjusting RED SAF entities until the schedule is once again feasible and REDSAF entities per time period are maximized.

Their solution approach also makes the following assumptions:

(a) the scheduling horizon is composed of finite, discrete, one hour periods, and

(b) training scenarios *always* start and end on the hour.

A given training scenario specifies the REDSAF requirements. McGinnis and Phelan treat REDSAF as a decision variable with the resulting schedule possibly reflecting a training level different than that specified by the unit being trained. In other words, a fully trained unit may not receive the full 100% REDSAF required for the scenario, but only a percentage of that amount (for example, 92%).

2.5 Summary

The various heuristic approaches to the RCPSP that minimize makespan may provide a solution that maximizes resource utilization in those cases where all training scenarios must be scheduled. The approach will guarantee a schedule that satisfies all temporal and resource constraints. Busch and Mulvey (1996) considered resource constraints of aircraft in their scheduling algorithm but did not attempt to maximize resource use or use dynamic time periods. They simply generated a feasible schedule "estimate." Sampson and Weiss (1995) assumed that the time periods were fixed (nonoverlapping) throughout the planning horizon. For CCTT scheduling, differing scenario durations violate this assumption. Yang and Ignizio (1987) assumed sharing

training resources which may or may not be possible in the CCTT configuration. McGinnis and Fernandez (1994b) were able to *optimally* solve scheduling decisions and policy in the basic training problem using dynamic programming because of the particular structure of the problem. However, this is nearly impossible in the CCTT scheduling problem where there may be thousands of training scenarios, hundreds of thousands of scheduling combinations in the planning horizon, and up to 3.47×10^{37} REDSAF decision outcomes (McGinnis and Phelan, 1996).

In their solution approach, McGinnis and Phelan (1996) considered *only* the REDSAF resource constraint in generating a "good" CCTT schedule with their hybrid expert system. No consideration was given to manned modules, SAF workstations, or After Action Review (AAR) stations. Each of these resources can individually affect the feasibility of a CCTT schedule.

None of the works previously discussed, however, simultaneously incorporate fixed resources, varying event durations (time periods), multiple resource requirements per event, multiple events per time period, precedence relationships among events, and the possibility of scheduling only a subset of identified training scenarios. The hybrid expert system developed by McGinnis and Phelan is currently the only known scheduling "tool" available to the Army for scheduling CCTT training. The schedule developed by the expert system generally is resource infeasible. To be useful to CCTT managers, the candidate schedule needs to "repaired" to establish a feasible schedule.

In order to identify a way to schedule the training scenarios (i. e., how do we schedule?), it is necessary to know what the objective is for scheduling the scenarios. Training schedules are often developed with the idea of training effectiveness in mind. Users want to measure how well an event (exercise) obtains its desired effect. But, there are no good direct measures of training effectiveness. With the significant per unit cost of a CCTT system in mind, the author felt that Army leaders and CCTT system managers would be very interested in resource utilization. *Maximizing* resource utilization with fixed resources and precedence relationships, or equivalently, minimize slack (unused) resources seemed to provide a reasonable scheduling objective. Now that the objective has been identified, how do we schedule the scenarios to minimize slack resources? A "greedy" heuristic provides a viable tool for doing this and guarantees a feasible schedule will be generated because all resource constraints are satisfied at each stage. It is known that this approach is not optimal, but it is widely used as giving good results (Gould, Eppen, and Schmidt, 1993).

Because of the number of various resource types in the CCTT problem, improvement procedures were not developed. However, the heuristic approach in this research will simultaneously satisfy all resource constraints and precedence relationships by scheduling scenarios (activities) in dynamic stages. The stages correspond to scenario completion times.

The methodology presented in this thesis attempts to provide an alternative CCTT scheduling approach that accounts for all relevant scenario and system factors. Unlike the

heuristic approach used in the expert system , this methodology generates a CCTT schedule by remaining feasible from start to end. The proposed approach focuses on maximizing resource utilization.

CHAPTER 3

DEVELOPMENT OF THE TRAINING SCENARIO SCHEDULING PROBLEM (TSSP) SCHEDULING HEURISTIC

3.1 Introduction

The general problem faced by CCTT managers is one of scheduling a subset of candidate training scenarios that will meet a specific training objective in a way that maximizes resource utilization. Because of the significant investment in CCTT facilities, it is desired that the facilities be used as much as possible (resource utilization) and that utilization is high. In addition, when using an optimal aproach, maximizing resource utilization will minimize the duration required for completion of all scenarios to be scheduled (makespan).

It is assumed that the resource requirements for each training scenario are known with certainty, and that the duration of a training scenario is also known. The scenario duration includes any administrative setup time, actual training time, and the duration of the after action review (AAR) sessions. In practice, the units being trained submit a list of training scenarios that they want to exercise. The scenarios are selected by the unit in order to satisfy their training objectives while considering the current level of training of the individual unit (untrained (U), partially trained but requiring practice (P), and trained

(T)). It is anticipated that units may select several alternative scenarios that satisfy a given training objective. In this case, only one of the set would have to be scheduled.

If it is required that all training scenarios have to be scheduled, then the training scenario scheduling problem (TSSP) may be represented as a traditional resource-constrained project scheduling network. Recall that the objective in the TSSP is to maximize resource utilization. Because minimizing makespan will simultaneously maximize resource utilization, any resource-constrained project scheduling problem algorithm that minimizes makespan could be used to solve the TSSP. However, in order to allow for the possibility that only a subset of the training scenarios and not the entire set needs to be scheduled, a more flexible algorithm is required. The heuristic developed below provides the capability for selecting a subset of alternative scenarios. However, in the description, the heuristic is restricted to that of scheduling all selected training scenarios. Extension to the more general case is addressed in future work.

The TSSP, as any scheduling problem, can be represented as a multi-stage decision process. Each stage is defined as the completion of a training scenario and the decision at each stage is to determine which scenario(s) to schedule next. The process continues until all scenarios are scheduled.

The proposed algorithm is structured as a dynamic algorithm where the scheduling decision at each stage is made based on relevant temporal and resource constraints at each stage. Although minimizing makespan and maximizing resource utilization are equivalent when the problem is solved optimally, it is not clear that using either criteria in a heuristic

will result in the complementary solution. Therefore, because the primary concern is maximizing resource utilization, it will be the criterion used at each decision stage when scheduling scenarios. The algorithm follows an approach similar to the LCBA approach of Ulusoy and Özdamar (1994). Specifically, the algorithm solves a zero-one integer programming problem at each stage to determine the locally optimized schedule that minimizes slack (idle) resources while satisfying any precedence and other temporal constraints.

A decision variable is defined for each scenario and a one is assigned if the scenario is selected during the current stage (time period) and a zero is assigned otherwise. At each stage, the algorithm minimizes the amount of unused resources, or "slack." This local minimization of idle resources is a heuristic approach for maximizing resource utilization over the entire schedule. As previously mentioned, minimizing idle resources is equivalent to maximizing resource utilization. Precedence relationships and special considerations are established using the assumptions in section 1.4. The general structure of the *algorithm* for this heuristic is shown in Table 1.

This algorithm represents a *greedy* heuristic approach to solving the CCTT scheduling problem. It decomposes the problem into decision stages and selects the scenario(s) that maximize resource utilization at each stage while simultaneously satisfying all resource constraints and precedence relationships. This process continues until all scenarios are scheduled. Although greedy heuristics are known to be optimal in only a limited number of instances, they are often used to identify "good" solutions in many

applications. In the present case, the greedy heuristic generates a feasible solution with "good" resource utilization. The resulting schedule could be improved by the use of an exchange heuristic (e. g., pairwise exchange). However, improvement of the CCTT schedule is beyond the scope of this research.

Table 1

Algorithm for the TSSP Scheduling Heuristic

Step 0: Identify levels of available resources and training scenarios to be scheduled.
Step 1: Schedule unscheduled scenarios to maximize resource utilization with respect to temporal and resource constraints. If all scenarios have been scheduled, STOP.
Step 2: Find first scenario(s) finished (advance to next next stage), and add resources released from the completed scenario to the available (unused) resources. Go to Step 1.

3.2 Mathematical Notation

The following notation is used in the development of the TSSP algorithm.

J: Index set for stages in the scheduling horizon, $J = \{1,2,...\}$;

j: Index for stage of the scheduling horizon, $j \in J$;

I: Index set of training scenarios $I = \{1,2,...\}$;

i: Index for training scenario number, $i \in I$;

K: Index set of resource types, $K = \{1, 2, ...\}$

k: Index for type of resource, $k \in K$;

SS_j : Index set of scenarios scheduled at beginning of stage *j*;

SC_j: Index set of scenarios completed at beginning of stage *j*;

CO_j: Index set of *all* completed scenarios at beginning of stage *j*;

SU_j : Index set of unscheduled scenarios at stage *j* (after scenarios are scheduled at the beginning of stage *j*);

C_j: Index set of current scenarios at stage *j* (those continuing and those scheduled at stage *j*);

R_j: Index set of continuing scenarios remaining at stage *j*;

RS_k:Set of related scenarios that must precede scenario *k*, $|RS_k|$ represents the cardinality of the group (number in the group)

a_{ik} : Technological coefficients, amount of resource type *k* needed by scenario *i*;

x_{ij} : Binary decision variable for scenario *i* scheduled at stage *j*;

y_{ij} : Binary variable for the completion of scenario *i* prior to stage *j*, $i \in CO_j$;

b_{kj} : Resource capacity, available resource type *k* at stage *j*;

u_{kj} : Slack variable for resource type *k* at stage *j*;

d_i : Duration in hours of scenario *i*;

s_i : Start time of scenario *i*;

f_i : Finish time of scenario *i*;

t_j : Time of stage *j*;

The following convention is used:

(a) $S + T = \{x \mid x \in S \cup T\}$, and

(b) $S - T = \{x \mid x \in S,\ x \notin T\}$

3.3 Decision Variables

One discrete binary decision variable is used to determine the scheduling of a scenario at a particular stage during the scheduling horizon. The decision variable, x_{ij}, is equal to one if scenario i is scheduled during stage j and zero otherwise. It is defined as:

$$x_{ij} = \begin{cases} 1 \text{ } \textit{if scenario i is scheduled during stage j} \\ 0 \text{ } \textit{otherwise} \end{cases}$$

3.4 Objective Function

The objective function is to minimize the sum of the slack variables (unused resources) for each resource type k at stage j :

$$\textit{Minimize} \sum_{k \in K} u_{kj} \tag{1}$$

This objective function is used iteratively as the scheduling advances from one stage (time period) to the next. The various resource types could be weighted if desired. However, in this application, all resource types are considered equally important.

3.5 Resource Constraints

Generally, resource constraints are written as:

$$\sum_{i \in SU_{j-1}} a_{ik}\, x_{ij} \;\leq\; b_{kj} \qquad \text{for all } k \in K, j \in J \tag{2}$$

where the sum of each resource type used in all scheduled scenarios at stage j does not exceed the system capacity. However, the resource types and quantities available for scheduling subsequent scenarios are *dynamic*, varying from stage to stage. Specifically, at stage $j = 1$ (initial scheduling stage where $t_I = 0$), the constraint is written as:

$$\sum_{i \in I} a_{ik}\, x_{i,1} + u_{k,I} \;=\; b_{k,I} \qquad \text{for all } k \in K \tag{3}$$

For the remaining scheduling stages ($j > 1$), these resource constraints are written as:

$$\sum_{i \in SU_{j-1}} a_{ik}\, x_{ij} + u_{kj} \;=\; b_{k,I} \;-\sum_{i \in R_j} a_{ik}\, x_{i,j-1} \qquad \text{for all } k \in K, j > I \tag{4}$$

where the sum of each resource type used in all scheduled scenarios at stage j equals system capacity minus resources used in continuing scenarios from the previous stage. For all $i \in R_j$, we reset continuing scenarios equal to one at stage j, or $x_{ij-1} = 1 = x_{ij}$.

To ensure that system capacity for the number of simultaneous exercises is not exceeded, the following constraint equation is used:

$$\sum_{i \in C_j} x_{ij} \leq 5 \tag{5}$$

3.6 Logical Constraints

Logical constraints are used to represent precedence relationships or other special conditions that must be strictly adhered to during the development of a feasible CCTT schedule.

3.6.1 Scheduling Simultaneous Scenarios

For scheduling considerations where two or more scenarios must be scheduled at the same stage (this occurs when a company sized unit wishes to train all three platoons simultaneously), the constraints are written as:

$$x_{ij} = x_{kj} \tag{6}$$

where x_{ij} represents the scenario associated with, for example, platoon #1 (scenario i), and x_{kj} represents the scenario associated with platoon #2 (scenario k). This constraint equation may be used for up to four pairs of scenarios (that is, up to five scenarios may be required to be scheduled at the same stage provided resource capacities are not exceeded).

The user of this algorithm must verify that the system resource capacities are not exceeded by the sum of the requested simultaneous scenarios *before* entering the constraint in the scheduling program or else the constraints will be infeasible.

3.6.2 Establishing Precedence Relationships

There may be occasions when it is required that one training scenario be completed before another scenario starts. For example, it may be necessary to schedule an untrained scenario (U) before scheduling trained (T) scenario for a given unit. All precedence relationships are represented using *pairs* of scenarios. Suppose that scenario i must precede scenario k (i. e., $f_i \leq s_k$). Then the set of related scenarios is $RS_k = \{i|$ scenario i precedes scenario $k\}$. In this case, another binary variable (y_{ij}) must be introduced. |It is defined as:

$$y_{ij} = \begin{cases} 1 \text{ } if \text{ } scenario \text{ } i \text{ } has \text{ } ever \text{ } been \text{ } completed \text{ } prior \text{ } to \text{ } stage \text{ } j \text{ } (i \in CO_j) \\ 0 \text{ } otherwise \end{cases} \tag{7}$$

Two constraints are used for the precedence relationship. The first constraint ensures that *only* one of the related scenarios can be selected for scheduling at stage j. It is written as:

$$\sum_{i \in RS_k} x_{ij} \leq 1 \tag{8}$$

The second constraint establishes the dependency relationship between scenarios i and k is written as:

$$x_{kj} \leq y_{ij} \tag{9}$$

where $y_{ij} = 1$ when scenario i is finished and remains one for all remaining scheduling stages. Only when $y_{ij} = 1$ can x_{kj} be "eligible" for scheduling. y_{ij} is considered the independent scenario and x_{kj} the dependent scenario. In the scheduling algorithm, $x_{ij} + y_{ij} \leq 1$ means that once scenario i has been completed, it cannot be scheduled again. This equation does not relate two separate scenarios, but the same scenario. It ensures that either its x or y value may be equal to one, but not both.

It may be necessary to establish a precedence relationship between a scenario and a group of scenarios. For example, it may be desired to schedule all platoon scenarios before scheduling any company scenarios. Let RS_k be a set of related scenarios that must be scheduled before scenario k can be scheduled. Equation 8 is generalized as follows:

$$x_{kj} \leq \frac{\sum_{i \in RS_k} y_{ij}}{|RS_k|} \tag{10}$$

where the sum of the y_{ij}s (scenarios completed) divided by the number of scenarios in the related group yields a value of one. When this occurs, the problem is solved exactly like

Equation 9. A value of one for the right hand side of the inequality leaves the left hand side free to be either zero or one.

Precedence relationships may be necessary for the following scheduling situations or combinations of situations:

(a) Priorities of training proficiency must be enforced (i. e., untrained units must be scheduled before partially trained units or trained units),

(b) Training unit elements must train in a specific sequence (i. e., platoons before companies and companies before battalions), and

(c) Multiple scenarios selected by a single unit must be sequenced. For example, first platoon must first conduct the "movement-to-contact" scenario, then the "deliberate attack" scenario, and last, the "defense-in-sector" scenario.

The user of the CCTT scheduler should verify that precedence relationships are absolutely required because the algorithm will *strictly* enforce any scheduling restrictions. The additional requirements may cause some scenarios to be delayed thereby reducing resource utilization.

3.7 State Transition Equations

To account for the stage of the system and associated transitions, it is necessary to define various event times and scenario sets.

3.7.1 Event Times

The *start* time for a scenario is:

$$s_i = t_j \quad \text{if } x_{ij} = 1 \text{ and } x_{ij-1} = 0 \tag{11}$$

$$\text{or} \quad s_i = t_j \quad (i \in SS_j)$$

Finish time for each scenario is determined by adding the total scenario duration time (in hours) to its start time (s_j). It is written as:

$$f_i = s_i + d_i \tag{12}$$

3.7.2 Scenario Set Definitions

The set of scenarios scheduled at stage j is:

$$SS_j = \{i \mid x_{ij} = 1 \text{ and } x_{i,j-1} = 0 \ \ (s_i = t_j)\} \tag{13}$$

$$\text{or} \quad SS_j = \{i \mid x_{ij} = 1,\ i \notin R_j\}$$

The set of continuing scenarios running at stage j is:

$$R_j = \{ i \mid x_{ij} = 1 \text{ and } x_{ij-1} = 1 \ (s_i \leq t_j \ , f_i > t_j)\} \tag{14}$$

$$\text{or } R_j = C_{j-1} - SC_j$$

The set of scenarios completed at the beginning of stage j is:

$$SC_j = \{ i \mid f_i = t_j \} \tag{15}$$

The set of *all* completed scenarios at the beginning of stage j is:

$$CO_j = \bigcup_{i=1}^{j} SC_i \tag{16}$$

$$\text{or } CO_j = CO_{j-1} + SC_j$$

The set of current scenarios at the stage j is:

$$C_j = R_j \cup SS_j \tag{17}$$

The set of remaining unscheduled scenarios (after scheduling) at stage j is:

$$SU_j = I - CO_j - C_j \tag{18}$$

or $$SU_j = SU_{j-1} - SS_j$$

3.7.3 Determining Scheduling Stages

To advance from one stage to the next, we simply find the shortest remaining scenario duration from the current stage.

The following equation defines this process:

$$t_{j+1} = \min_i \{ f_i \mid i \in C_j \} \quad \text{for } j \geq 0 \tag{19}$$

where t_{j+1} is the time of the next scheduling stage.

3.8 TSSP Scheduling Algorithm

The structure of the algorithm given in Table 1 provides the basic rationale. The following detailed algorithm provides the exact structure.

3.8.1 Initializing the Algorithm

Before applying the algorithm, the following variables are initialized as follows:

(a) Initialize x_{ij}, y_{ij}, and $b_{k,1}$ where $b_{k,1}$ equals initial resource capacities.

(b) Define RS_k.

(c) Set SU_j equal to I, the set of all scenarios, and $SU_1 = I$.

(d) Set R_j, C_j, SS_j, CO_j, and SC_j equal to the empty set (ϕ) (R_1, C_1, SS_1, CO_1, and SC_1 equal ϕ).

(e) Set $t_j = 0$ ($t_1 = 0$).

3.8.2 Stage By Stage Implementation of the Algorithm

The following section describes the detailed stage by stage process used to implement the TSSP algorithm.

(a) Initial Stage (Stage = 1, $t_1 = 0$):

<u>Step 1</u>. Solve the following zero-one integer program at the beginning of stage one:

$$\text{MINIMIZE} \sum_{k \in K} u_{k,1}$$

subject to:

$$\sum_{i \in I} a_{ik} x_{i,1} + u_{k,1} = b_{k,1}, \quad k \in K$$

$$\sum_{i \in I} x_{i,1} \leq 5$$

$$x_{kj} \leq \frac{\sum_{i \in RS_k} y_{ij}}{|RS_k|}$$

$$x_{i,1} = \{0, 1\}$$

<u>Step 2</u>. Set $SS_1 = \{i \mid x_{i,1} = 1\}$, $SU_1 = I - SS_1$, $C_1 = SS_1$, $R_1 = \phi$ $CO_1 = \phi$, $s_i = 0$, $f_i = d_i$ $(i \in SS_1)$.

Step 3. Test for completion of scheduling: If $SU_1 = \phi$, then STOP (all scenarios have been scheduled), otherwise continue with $j = 2$.

Step 4. Find the time of the next scheduling stage:

$$t_2 = \min_i \{ f_i \mid i \in C_{j-1} \ (C_1) \}.$$

(b) Second and Subsequent Stages

Step 1. Set $SC_j = \{ i \mid f_i = t_j \}$, $R_j = C_{j-1} - SC_j$, $CO_j = CO_{j-1} + SC_j$, $y_{ij} = 1$, $i \in SC_j$.

Step 2. Solve the following zero-one integer program at the beginning of stage two:

$$\text{MINIMIZE} \sum_{k \in K} u_{k,j}$$

subject to:

$$\sum_{i \in SU_{j-1}} a_{ik} x_{ij} + u_{kj} = b_{k,1} - \sum_{i \in R_j} a_{ik} x_{i,j-1} \quad (k \in K)$$

$$x_{ij} = x_{ij-1} = 1 \quad (i \in R_j)$$

$$\sum_{i \in SU_{j-1}} x_{ij} \leq 5 - \sum_{i \in R_j} x_{ij}$$

$$x_{kj} \leq \frac{\sum_{i \in RS_k} y_{ij}}{|RS_k|}$$

$$x_{ij} = \{0, 1\}$$

Step 3. Set $SS_j = \{i \mid x_{ij} = 1, i \notin R_j\}$, $s_i = t_j$ $(i \in SS_j)$, $f_i = s_i + d_i$ $(i \in SS_j)$,

$C_j = R_j + SS_j$, $SU_j = SU_{j-1} - SS_j$

Step 4. Test for completion of scheduling: If $SU_j = \phi$, then STOP (all scenarios have been scheduled), otherwise continue with $j = j + 1$.

Step 5. Find the time of the next scheduling stage:

$t_{j+1} = \min_i \{ f_i \mid i \in C_j\}$. Go to Step 1.

3.9 Summary

In this chapter, mathematical definitions (both terms and sets), problem structure (objective function and constraints), mathematical formulas, and the state transition equations for the TSSP Scheduling Heuristic were developed. The general and specific theoretical applications of the TSSP Scheduling Heuristic are described in the next chapter along with a detailed description of how the algorithm was implemented using *Microsoft Excel®*. This description includes a detailed account of how the spreadsheet and *Excel* functions were used to incorporate the information introduced in Chapter 3. The results of implementing the TSSP Scheduling Heuristic using *Excel* are discussed in Chapter 5.

CHAPTER 4

IMPLEMENTATION OF THE TSSP SCHEDULING HEURISTIC

Using the detailed description of the TSSP Scheduling Heuristic from Chapter 3, implementation of the algorithm is now possible. This chapter includes a description of the training scenarios used, use of the *Excel* functions and the Solver tool (for solving the integer program for both resource and precedence constraints), and a stage by stage implementation of the algorithm.

4.1 Scenarios

A total of twenty-five scenarios, six company and nineteen platoon, were randomly selected to test the algorithm. Table 2 shows the scenarios used for testing the algorithm including resource requirements and scenario durations.

Scenarios include both "standard" and "nonstandard" resource requirements. *Standard* refers to resource requirements that are normally used to conduct exercises at a given unit level and in a given training context. For example, an armor platoon conducting a movement-to-contact within a company training context would normally require four M1 simulators, two SAF workstations, and one AAR station to conduct a platoon exercise. To operate in a platoon training context, it would normally require four

M1A1/A2 simulators, one SAF workstation, and one AAR station. The standard resource requirements for scenarios are shown on Table 3.

Table 2

Scenario Profile

		Resource Requirements								Scen.
Scen. #	Unit Size	M1	M2	DI	HV	SAF	AR	PC	FV	Duration
X1	PLT	4	0	1	1	3	1	0	0	2.12
X2	PLT	4	2	1	3	3	2	0	0	3.27
X3	PLT	4	0	0	0	2	1	0	0	2.19
X4	PLT	4	3	1	0	2	1	1	1	2.49
X5	PLT	4	2	0	1	1	1	1	0	2.39
X6	PLT	1	4	1	1	3	1	0	0	2.45
X7	PLT	2	4	1	1	3	1	0	0	2.47
X8	PLT	3	4	0	0	1	1	1	1	3.12
X9	PLT	0	4	0	0	1	1	0	0	2.1
X10	CO	7	4	2	2	3	3	2	2	3.38
X11	CO	7	4	2	2	3	2	2	2	3.47
X12	PLT	5	5	1	1	2	1	2	1	3.22
X13	CO	4	7	2	1	3	1	2	2	3.42
X14	CO	7	7	2	2	3	3	3	2	3.59
X15	PLT	4	1	1	1	3	1	0	0	2.41
X16	PLT	4	2	1	3	3	1	0	0	2.48
X17	PLT	4	3	0	0	2	2	1	1	3.3
X18	PLT	4	0	1	0	2	1	0	0	2.11
X19	PLT	4	1	0	1	1	1	0	0	2.36
X20	PLT	1	4	1	1	3	1	0	0	2.28
X21	PLT	2	4	1	1	3	1	0	0	2.24
X22	PLT	0	4	0	0	1	1	0	0	2.31
X23	PLT	2	4	0	0	1	1	1	1	2.51
X24	CO	7	4	2	2	3	2	2	2	3.45
X25	CO	7	4	2	2	3	2	2	2	3.55

Nonstandard refers to any resource requirement other than those shown on Table 3. Using the example above, the armor platoon may be one tank crew short and still conduct the platoon exercise (they would require only three M1A1/A2 simulators).

Table 3

Standard Resource Requirements (TRADOC, 1993)

Unit Type	TRG Unit	TRG Context	Mission	Red SAF	Blue SAF	SAF WS	Resource Requirements M1	M2	DI	HV	PC	FV	OC	AR
Armor	PLT	PLT	ATK	23	0	1	4	0	0	0	0	0	32	1
			MTC	20	0	1	4	0	0	0	0	0	27	1
			DEF	65	0	1	4	0	0	1	0	0	33	1
Mech Inf.	PLT	PLT	ATK	23	0	1	0	4	2	0	0	0	32	1
			MTC	20	0	1	0	4	2	0	0	0	27	1
			DEF	65	0	1	0	4	2	1	0	0	33	1
Armor	PLT	CO	ATK	29	39	2	4	0	0	0	0	0	102	1
			MTC	62	12	2	4	0	0	0	0	0	84	1
			DEF	176	23	4	4	0	0	0	0	0	97	1
Mech Inf.	PLT	CO	ATK	29	39	2	0	4	2	0	0	0	102	1
			MTC	62	12	2	0	4	2	0	0	0	84	1
			DEF	176	27	4	0	4	2	0	0	0	97	1
Armor	CO	CO	ATK	29	27	2	10	4	2	1	1	1	99	2
			MTC	62	0	1	10	4	2	1	1	1	81	2
			DEF	176	11	4	10	4	2	1	1	1	94	2
Mech Inf.	CO	CO	ATK	29	27	2	4	10	4	1	1	1	99	2
			MTC	62	0	1	4	10	4	1	1	1	81	2
			DEF	176	15	4	4	10	4	1	1	1	94	2
Armor	CO	BN	ATK	65	64	2	10	4	2	1	1	1	168	3
			MTC	138	73	4	10	4	2	1	1	4	135	3
			DEF	491	85	10	10	4	2	1	1	1	189	3
Mech Inf.	CO	BN	ATK	65	88	3	4	10	4	1	1	1	164	3
			MTC	138	93	4	4	10	4	1	1	4	135	3
			DEF	491	101	10	4	10	4	1	1	1	185	3
Armor or Mech Inf.	BN	BN	ATK	65	0	1	14	44	18	4	1	4	158	5
			MTC	138	9	3	14	44	18	2	1	4	134	5
			DEF	491	17	9	14	44	18	4	1	4	158	5

Numerous resource combinations can be made by altering the normal resource requirements for a given training scenario. The nonstandard resource requirements used to test the algorithm were considered reasonable by experts consulted by the author (Wilkinson, personal communication January 21, 1997).

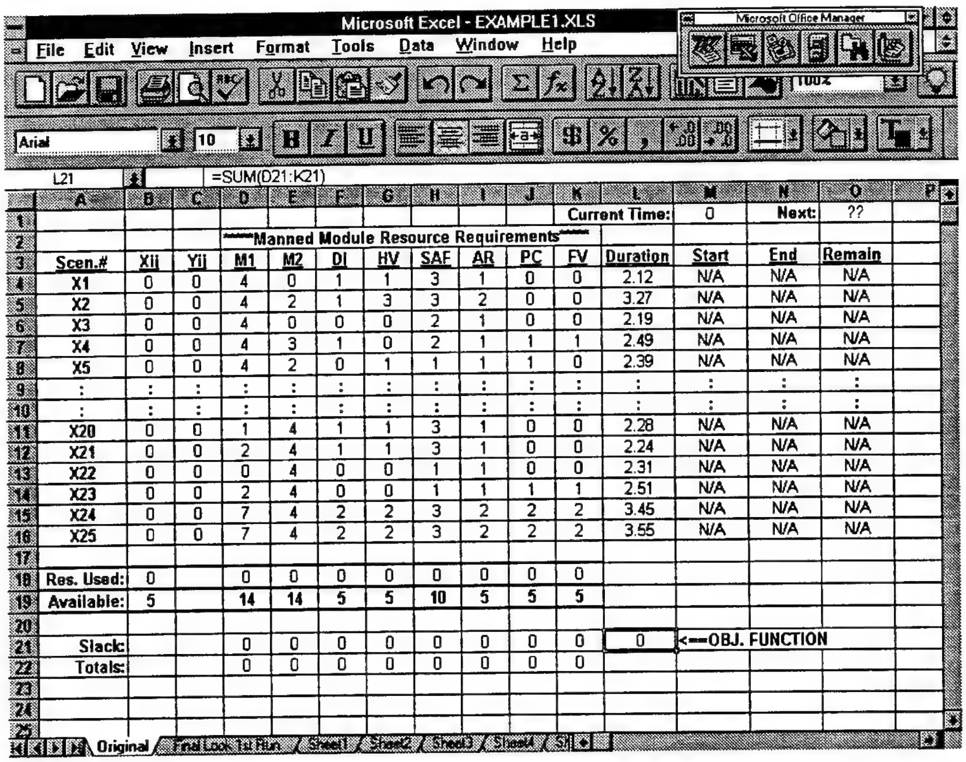
4.2 Spreadsheet Description

The TSSP scheduling algorithm was implemented in a spreadsheet environment using *Microsoft Excel®* in order to demonstrate the capability of the algorithm. Because each scheduling decision involves the solution of a zero-one integer program, the *Excel* Solver was used for the scheduling decision at each stage. The spreadsheet was developed so that subsequent stages would be contained on subsequent "tabs" in the workbook. In figures 3 and 4, the row of slack variables and the x_{ij} column were initialized at zero. Since the algorithm has not yet been applied to the problem, zero values for the row of slack variables and the x_{ij} decision variables are shown in both spreadsheet figures.

Figure 3 shows an abridged version of the actual *Microsoft Excel®* spreadsheet where scenarios six through nineteen are deleted in order to show the "bottom half" of the spreadsheet. It is used in sections 4.2.1 through 4.2.12 to explain the implementation of the algorithm.

4.2.1 Scenario Numbers

Cells A4 through A16, written as A4-A16, represent the training scenario numbers X1 through X25 and are used only for scenario identification. Scenario numbers X10, X11, X13, X14, X24, and X25 are the company level scenarios. All other scenarios are platoon scenarios.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1												Current Time:	0	Next:	??
2				*****Manned Module Resource Requirements*****											
3	Scen.#	Xii	Yii	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
4	X1	0	0	4	0	1	1	3	1	0	0	2.12	N/A	N/A	N/A
5	X2	0	0	4	2	1	3	3	2	0	0	3.27	N/A	N/A	N/A
6	X3	0	0	4	0	0	0	2	1	0	0	2.19	N/A	N/A	N/A
7	X4	0	0	4	3	1	0	2	1	1	1	2.49	N/A	N/A	N/A
8	X5	0	0	4	2	0	1	1	1	1	0	2.39	N/A	N/A	N/A
9	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
10	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
11	X20	0	0	1	4	1	1	3	1	0	0	2.28	N/A	N/A	N/A
12	X21	0	0	2	4	1	1	3	1	0	0	2.24	N/A	N/A	N/A
13	X22	0	0	0	4	0	0	1	1	0	0	2.31	N/A	N/A	N/A
14	X23	0	0	2	4	0	0	1	1	1	1	2.51	N/A	N/A	N/A
15	X24	0	0	7	4	2	2	3	2	2	2	3.45	N/A	N/A	N/A
16	X25	0	0	7	4	2	2	3	2	2	2	3.55	N/A	N/A	N/A
17															
18	Res. Used:	0		0	0	0	0	0	0	0	0				
19	Available:	5		14	14	5	5	10	5	5	5				
20															
21	Slack:			0	0	0	0	0	0	0	0	0	<==OBJ. FUNCTION		
22	Totals:			0	0	0	0	0	0	0	0				
23															
24															
25															

Figure 3. Abridged Excel spreadsheet for basic model (shows initial stage).

4.2.2 Scheduling Decision Variables

Cells B4-B16 represent the zero-one integer decision variables for the corresponding scenario numbers in the "A" column. These cells are part of the "changing

cells" in the *Excel* Solver. Changing cells are the cells (values) that are manipulated to try to optimize the problem at a particular scheduling stage. If a scenario is selected, then its cell value is one; otherwise, it remains zero. Appropriately, the heading for this column is x_{ij} to coincide with the mathematical formulation of the problem discussed in Chapter 3.

4.2.3 Zero-One Variable for Precedence Relationships

Cells C4-C16 represent the zero-one integer values for all completed scenarios. Completed scenarios are given a value of one that remains constant throughout the remainder of the planning horizon. The heading for this column is y_{ij} (see Equations 9 and 10). It is used in the algorithm for establishing precedence relationships.

4.2.4 Resource Capacities

The resources located at CCTT sites may vary depending upon the types and quantities of units stationed at the CCTT facility location. Therefore, the formulation of this problem must allow for changes to the resource types and capacities. A common CCTT site configuration was selected for use as an example. A total of eight separate resource types were considered:

14 each M1A1/A2 Tank and M2A2 Bradley simulators

10 Semi-automated forces (SAF) workstations

5 each DIM, HMMWV, M113A3 (APC), and FIST-V simulators

5 AAR stations

The resource capacities listed above represent the actual site allocations for M1A1/A2, M2A2, SAF workstations, and AAR stations. The other resource capacities were slightly increased in order to fully test the application of the algorithm. They are *not* the actual site allocations for a CCTT site. Changes to any of these resources, however, are easily accomplished by updating the appropriate Excel worksheet "cell". Cells D19-K19 contain the resource capacities

4.2.5 Resource Requirements

Cells D4-D16, E4-E16, F4-F16, G4-G16, H4-H16, I4-I16, J4-J16 and K4-K16 represent the resource requirements for M1 modules, M2 modules, dismounted infantry modules, HMMWV modules, SAF workstations, AAR stations, APC modules, and FIST-V modules, respectively for each scenario. For example, cells D4-K4 shows the amount of each resource type required to run Scenario # 1 (X1). Resource requirements are fixed throughout the planning horizon. These resource requirements correspond to the scenario profile resources in Table 2.

4.2.6 Scenario Duration

Duration (cells L4-L16) refers to the time in hours required to complete each scenario. Duration times include administrative setup times as well as after action review times. Duration times for scenarios in the Army's scenario library were not exactly known when this research was conducted. Therefore, the times selected represent reasonable

approximations of duration times for each scenario type (platoon or company). For example, Scenario # 1 (platoon exercise) has a duration of 2.12 hours. Duration times are also fixed throughout the planning horizon.

4.2.7 Current Time

The *Current Time* cell (M1) represents the current time for each stage and was entered and updated manually. It was initialized at zero (the first scheduling stage) and updated at subsequent stages based upon the value in the "Next" cell (O1).

4.2.8 Scenario Start and End Times

Start and *End* columns (M4-M16, N4-N16) represent the times (stages) when scenarios are scheduled and completed (Equation 13). *Excel* functions and manual procedures were used to automatically record and update start and end times. Scenario start times were computed as:

$$\textit{Start} = \text{IF(B** = 1, M1, "N/A")} \tag{20}$$

where B** represents the respective decision variable (x_{ij}) cell, M1 is cell containing the current time, and "N/A" means the scenario has either been completed or not yet scheduled.

The *Excel* logic used in this formula is:

> If B** = 1 is true (scenario is selected at this stage), then cell value equals value of M1 (start time equals current time), else value of cell M** (respective start time) equals "N/A."

Scenario end times were computed as:

$$End = \text{IF}(B^{**} = 1, M1 + L^{**}, \text{"N/A"}) \tag{21}$$

where B** , M1, and "N/A" are the same as above and L** represents the respective scenario duration time. Similarly, the logic is:

> If B** = 1 is true (scenario is selected at this stage), then cell value equals M1 plus L** (end time equals current time plus scenario duration), else value of cell N** equals "N/A."

Because both start and end times were dependent on the current time (M1) via functions, a simple manual procedure was implemented to prevent these values from changing when transitioning from stage to stage. By overwriting times generated by formulas with the identical keypad numbers, it changed the contents of the cell from *function* values to a numeric values and removed cell referencing. This technique is termed "hardening" the cell contents. Now, when the algorithm advanced to the next stage and the current time was updated, the start and end time values remained the same as those from the previous stage. When scenarios had been completed, the "N/A" text

was entered for both the start and end times. Hardening the start and end times is also necessary to ensure that the time remaining for scheduled scenarios is properly updated and is discussed in the next section.

4.2.9 Time Remaining in Ongoing Scenarios

The term *Remain* (O4-O16) represents the time remaining, at each scheduling stage, of ongoing scenarios that have been selected in some previous stage. This column is updated automatically as the algorithm advances from one stage to the next. The following *Excel* function was used to automatically record and update time remaining in the scenario:

$$Remain = \text{IF(N** = "N/A", "N/A", N** - M1)} \tag{22}$$

where N** represents end time cells for respective scenarios, "N/A" and M1 are the same as before. The *Excel* logic used in this formula is:

> If N** = "N/A" is true (scenario is unscheduled or is completed), then cell value equals (remains) "N/A", else value of cell O** equals N** - M1 (time remaining equals end time minus current time).

The importance of ensuring that end time values are numbers and not formulas should be apparent here. As the algorithm advances to the next scheduling stage, both start and end times for scenarios would change from their correct values to the "new" current value

(time) as soon as cell M1 changed. Therefore, the time remaining would also change because it references the respective end time cell in its formula.

4.2.10 Next Stage Time

The *Next* cell displays, at the current scheduling stage, the time when the next scheduling stage will occur. The following *Excel* function was used to automatically record and update the time of the next scheduling stage:

$$Next = \text{MIN(O4:O16)} + \text{M1} \tag{23}$$

where MIN(O4:O16) represents the minimum *numeric* value in cells O4 through O16 (time remaining cells). *Excel* searches for the smallest numeric value in the cell range and adds it to the current time. To illustrate, if the smallest remaining time for all ongoing scenarios is .65 hours and the current time is hour 11.3, the cell will display a value of hour 11.95 as the next scheduling stage.

Using values of zero in the "time remaining" column to represent completed or unscheduled scenarios results in cells containing these zero values *always* being selected. Therefore, it is desirable to skip (not evaluate) the cells corresponding to completed or unscheduled scenarios. Using nonnumeric values, or text, in the "time remaining" cells for these scenarios resolves this problem because they are not evaluated by the MIN (cell range) function. The author selected "N/A" for this purpose.

4.2.11 Resources Used Computation

To record the amount of resources used at each stage of the planning horizon, *Excel's* "sum" and "sumproduct" functions were used. The total number of scenarios scheduled at each stage is the sum of the values in the x_{ij} column (cells B4 through B16). Thus, cell B18 contains the formula:

$$\textit{Number of Scenarios Used} = \text{SUM(B4:B16)} \tag{24}$$

Resources are tallied by multiplying the column of each resource type (D4-D16, E4-E16, ..., K4-K16) by the x_{ij} column (B4-B16) and then summing them. For example, cell D18 would contain the formula:

$$\textit{M1A1 Resources Used} = \text{SUMPRODUCT(B4:B16,D4:D16)} \tag{25}$$

This formula is repeated for each resource column.

4.2.12 Slack Variables and Objective Function

Slack variables representing unused resources are contained in cells D21-K21. Like cells B4-B16, these cells are also manipulated (changing cells) to try to optimize the problem at a particular scheduling stage. Values of the slack variables at each scheduling stage are generated by the Solver function.

The *objective function* minimizes the sum of the slack variables in order to maximize resource utilization at each stage. Thus, cell L21 contains the formula:

$$L21 = \text{SUM(D21:K21)} \tag{26}$$

4.2.13 Totals

Resource *Totals* represent the sum of slack variables and the resources used for each resource type. For example, the total M1A1 resources is written as:

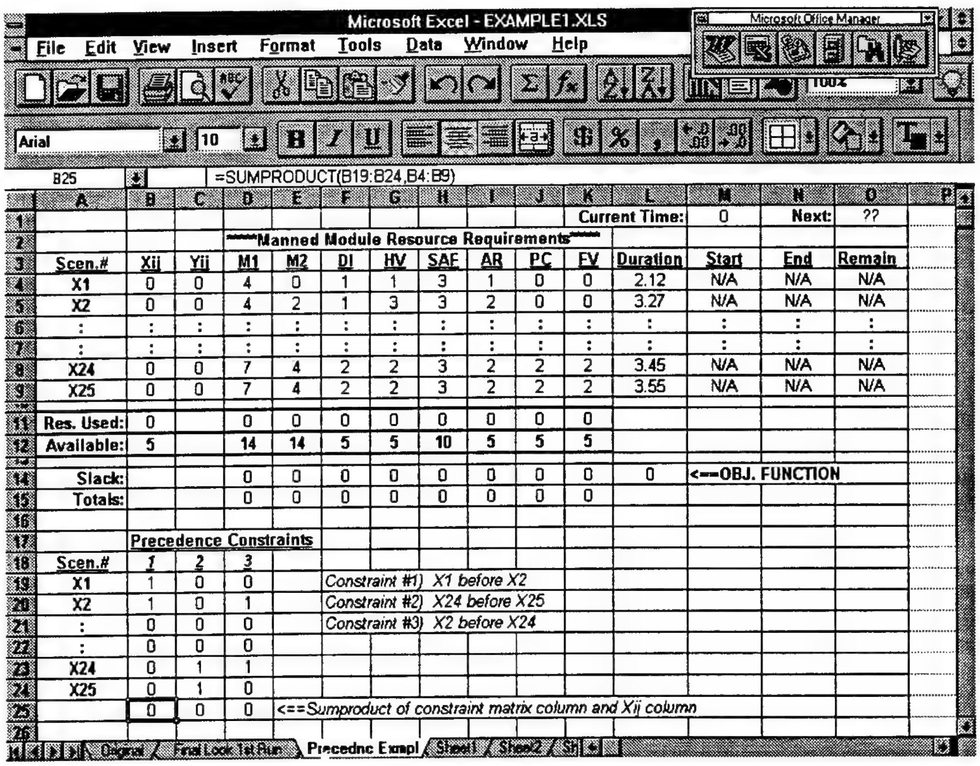
$$\textit{Total M1A1s Used} = \text{D18} + \text{D21} \tag{27}$$

where D18 is the number of M1A1s used at a particular stage and D21 is the M1A1 slack variable at that stage. Resource *Totals* and resources available are equal because resources used plus slack equals total resources available. For example, in figure 3, D22 would equal D19 after the algorithm is applied and remain so for all subsequent scheduling stages.

4.3 Establishing Precedence Relationships Using the Spreadsheet

Precedence relationships used in this research were of two types, (1) between two or more individual scenarios and (2) between groups of scenarios. The constraint, "X1 must be completed before X2," is an example of the first precedence relationship type and,

"all platoon scenarios must be completed before scheduling company scenarios," is an example of the second precedence relationship type. Figure 4 shows an example of how this precedence criteria can be used on the *Excel* spreadsheet. Although the constraints shown are not the actual constraints used for testing the algorithm, it shows the format required to solve problems with large numbers of precedence relationships.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1											Current Time:		0	Next:	??
2				*****Manned Module Resource Requirements*****											
3	Scen.#	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
4	X1	0	0	4	0	1	1	3	1	0	0	2.12	N/A	N/A	N/A
5	X2	0	0	4	2	1	3	3	2	0	0	3.27	N/A	N/A	N/A
6	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
7	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
8	X24	0	0	7	4	2	2	3	2	2	2	3.45	N/A	N/A	N/A
9	X25	0	0	7	4	2	2	3	2	2	2	3.55	N/A	N/A	N/A
11	Res. Used:	0		0	0	0	0	0	0	0	0				
12	Available:	5		14	14	5	5	10	5	5	5				
14	Slack:			0	0	0	0	0	0	0	0	0	<==OBJ. FUNCTION		
15	Totals:			0	0	0	0	0	0	0	0				
16															
17		Precedence Constraints													
18	Scen.#	1	2	3											
19	X1	1	0	0		Constraint #1) X1 before X2									
20	X2	1	0	1		Constraint #2) X24 before X25									
21	:	0	0	0		Constraint #3) X2 before X24									
22	:	0	0	0											
23	X24	0	1	1											
24	X25	0	1	0											
25		0	0	0	<==Sumproduct of constraint matrix column and Xij column										
26															

Figure 4. Abridged Excel spreadsheet showing precedence relationships.

4.3.1 Precedence Relationships Between Two or More Individual Scenarios

Recall from Chapter 3 that establishing a precedence relationship between two or more individual scenarios requires two constraints; one for ensuring that only one of the

related scenarios is chosen at a time (Equation 8), and one ensuring the independent scenario has been completed (Equation 9) before the dependent scenario is scheduled. Therefore, it is necessary to identify cells which contain the "summation" part of Equation 8 when establishing the "one-at-a-time" part of the precedence relationship. The author *enumerated* all five individual precedence relationships used in testing the algorithm. Those five relationships were: (1) X1 before X2, (2) X2 before X4, (3) X9 before X21, (4) X15 before X16, and (5) X17 before X12. As shown in Table 33, Appendix B, five separate cells were used to contain the summation part of Equation 8 for each one of them.

Large problems or problems with many individual precedence relationships may require keeping track of numerous summation functions. Enumeration may be too inefficient to meet this requirement. A more efficient way to represent numerous summation functions is to use a matrix. The number of rows in the matrix corresponds exactly to the total number of scenarios. The number of columns corresponds to the number of summation functions (Equation 8 constraints) needed. The matrix is initialized with all entries equal to zero. All related scenarios in a constraint are given a value of one in the appropriate constraint column. Summation "formulas" for each constraint are placed in a row of cells below the last matrix row and in their respective constraint column as shown in figure 4 (cells B25-D25). These cells can then be referenced by the Solver tool.

To illustrate, look at the example in figure 4. Note the number of rows in the matrix (A19-A24) corresponds exactly to the number of scenarios (A4-A9). There are three matrix columns (B19-B24, C19-C24, and D19-D24) because there are three precedence constraints in this example. Constraint #1 is represented by cells B19 - B24. The two related scenarios, X1 and X2, have a value of one in their respective cells in the constraint column. Cell B25 contains the summation function:

$$\textit{Cell B25} = \text{SUMPRODUCT(B19:B24,B4:B9)} \qquad (28)$$

where the constraint column (B19 - B24) is multiplied by the x_{ij} column (B4 - B9). Setting cell B25 $\leq$ 1 in the *Excel* Solver, ensures that only one of the two related scenarios can be selected at one time. Continuing with the example, suppose X1 and X2 are selected for scheduling at the same stage (B4 = 1, B5 = 1). The value produced by the function in cell B25 would be $(1\times1) + (1\times1) + (0\times0) + \ldots + (0\times0) = 2$. Since B25 must be less than or equal to one, this cannot occur. Therefore, only one of the scenarios can be scheduled at a time because only one x_{ij} in the set of precedence related scenarios can have a value of one (the other must be zero). Equation 28 generates the same net result as Equation 8, ensuring only one scenario is scheduled at a time. Computing the other two constraints is accomplished using the same procedure.

Now that only one of the related scenarios can be scheduled at a time, the second precedence relationship equation ensures that the dependent scenario is not scheduled

before the independent scenario. From section 4.2.3, when scenarios have been *completed* their respective y_{ij} variables equal one. Therefore, by setting the x_{kj} cell of the *dependent* scenario less than or equal to the related y_{ij} cell of the *independent* scenario, it is ensured that the "*k*th" scenario is scheduled *only after* the "*i*th" scenario has been completed. When the y_{ij} cell is zero (scenario is either currently ongoing or unscheduled), then the x_{kj} cell is also forced to be zero (cannot schedule). When the y_{ij} cell is one (scenario has been completed), then the x_{kj} cell can be either zero or one.

4.3.2 Precedence Relationships Between Scenario Groups

To ensure that a group of scenarios is completed prior to other scenarios being scheduled, the approach from the previous section can be extended. The method used in this research treated the group of *dependent* scenarios as individual scenarios and then related them (separately) to the *independent* group. For any one of the dependent scenarios to be selected for scheduling, every scenario in the independent group must be completed. This requirement is accomplished using Equation 10. Equation 10 will yield a value of one when all scenarios have been completed. By setting the x_{kj} cell of each *dependent* scenario less than or equal to the cell containing Equation 10, it is ensured that the precedence relationship holds. When this formula cell is anything less than one (none or some, but not all, of the scenarios have been completed), then the x_{kj} cell is forced to be zero because of the program's integer value requirement. When the y_{ij} (Equation 10) cell

is one (*all* scenarios in the independent group have been completed), then each of the x_{kj} cells can be either zero or one.

The author identified a single cell for containing Equation 10 in testing this group application of the TSSP algorithm (see Constraint #7, Table 34).

The matrix introduced in the previous section can also be used to perform this function. A column can be added to the matrix for each group constraint (Equation 10). The constraint column is multiplied by the y_{ij} column (completed scenarios) instead of the x_{ij} column. The sumproduct function at the "bottom" of the matrix is modified to include a divisor for the number of related scenarios in the group (*RS*).

To illustrate, *assume* the matrix column E19-E24 in figure 4 represented this group precedence relationship constraint (*not shown in the figure*) and X1, X2, and X24 are platoon scenarios (the independent group) that must be completed before X25 (the dependent scenario) can be scheduled. A value of one would be placed in cells E19, E20 and E23. The function in cell E25 would be:

$$\textit{Cell E25} = \text{SUMPRODUCT (C4-C9, E19-E24)/3} \tag{29}$$

where C4-C9 is the y_{ij} column (completed scenarios) and three is the number of scenarios in the group. Equation 29 handles the "summation" part of constraint Equation 10 exactly like Equation 28 did for constraint Equation 8 in the previous section. The difference, however, is that this cell is not set less than or equal to one, but is used for *referencing* by

the dependent scenarios. Continuing the example, B9 ≤ E25 means that the value of X25 (the company scenario) must be less than or equal to the value of cell E25. E25 is less than one when any *one* of the group of platoon scenarios has not been completed. Because of the integer reqirement of x_{ij}, the dependent scenario cannot be selected. Only when the value of E25 equals one can X25 be scheduled (B9 can be zero or one).

4.4 Using the Solver Tool in *Microsoft Excel®*

With all functions and cell references explained in the above sections, the implementation of the algorithm in the *Excel* Solver using the model in Appendix C is described below. This model includes individual precedence relationships, group precedence relationships and a requirement for three scenarios to be scheduled at the same stage. Figure 5 shows the Solver parameters for the initial scheduling stage. Although only six of the thirty constraints are shown in the figure, all of them are explained in section 4.4.3.

4.4.1 Target Cell

The *Set Target Cell* box references the objective function cell. For this model, M33 is the target cell that is being minimized

4.4.2 Changing Cells

The *By Changing Cells* box references cells that are manipulated in order to try to optimize the objective function. The changing cells are: E33:L33 (*slack* variables) and B4:B28 (x_{ij} decision variables).

4.4.3 Constraints

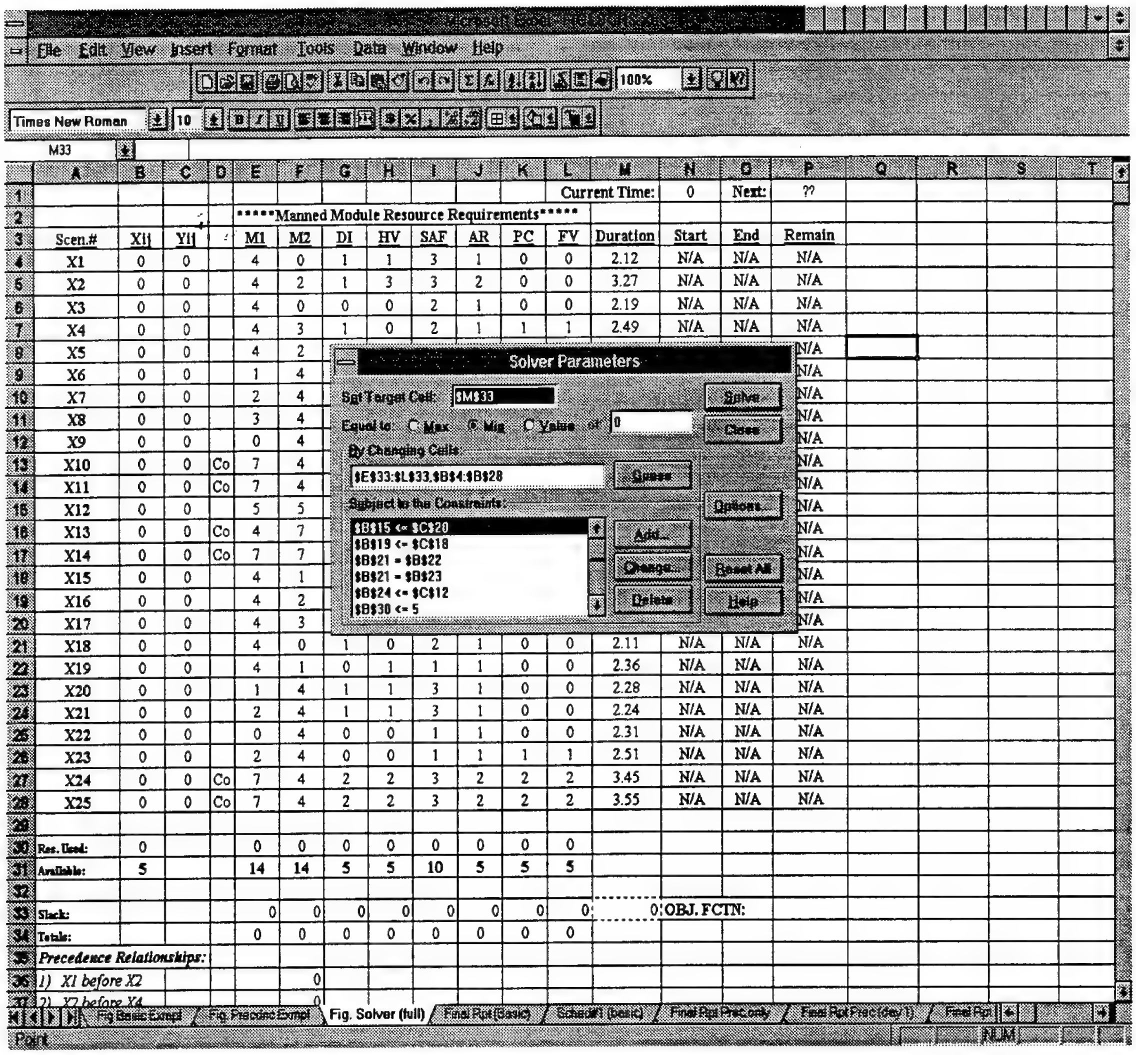
The *Subject to the Constraints* box references cells that are resource constraints, precedence relationships, or other conditions used to solve the problem. The first constraint shown in figure 5, B15 ≤ C20, is a precedence constraint between two individual scenarios. Specifically, it is X17 before X12. The other individual precedence constraints used in the Solver are: B19 ≤ C18 (X15 before X16), B24 ≤ C12 (X9 before X21), B5 ≤ C4 (X1 before X2), and B7 ≤ C5 (X2 before X4).

The two constraints B21 = B22 and B22 = B23 ensure that scenarios X18, X19, and X20 are scheduled at exactly the same stage.

The constraint B30 ≤ 5 ensures that the total number of simultaneous scenarios at any stage does not exceed five.

The constraints B4:B28 ≤ 1, B4:B28 ≥ 0, and B4:B28 = integer requires the decision variables to be either zero or one and disallows fractional values.

D13, D14, D16, D17, D27, and D28 ≤ I42 represents the group precedence constraint. Cell I42 contains Equation 10 and each of the company scenarios X10, X11, X13, X14, X24, and X25 reference that cell. This ensures that all platoon scenarios are



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1													Current Time:	0	Next:	??
2					*****Manned Module Resource Requirements*****											
3	Scen.#	Xij	Yij		M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
4	X1	0	0		4	0	1	1	3	1	0	0	2.12	N/A	N/A	N/A
5	X2	0	0		4	2	1	3	3	2	0	0	3.27	N/A	N/A	N/A
6	X3	0	0		4	0	0	0	2	1	0	0	2.19	N/A	N/A	N/A
7	X4	0	0		4	3	1	0	2	1	1	1	2.49	N/A	N/A	N/A
8	X5	0	0		4	2										N/A
9	X6	0	0		1	4										N/A
10	X7	0	0		2	4										N/A
11	X8	0	0		3	4										N/A
12	X9	0	0		0	4										N/A
13	X10	0	0	Co	7	4										N/A
14	X11	0	0	Co	7	4										N/A
15	X12	0	0		5	5										N/A
16	X13	0	0	Co	4	7										N/A
17	X14	0	0	Co	7	7										N/A
18	X15	0	0		4	1										N/A
19	X16	0	0		4	2										N/A
20	X17	0	0		4	3										N/A
21	X18	0	0		4	0	1	0	2	1	0	0	2.11	N/A	N/A	N/A
22	X19	0	0		4	1	0	1	1	1	0	0	2.36	N/A	N/A	N/A
23	X20	0	0		1	4	1	1	3	1	0	0	2.28	N/A	N/A	N/A
24	X21	0	0		2	4	1	1	3	1	0	0	2.24	N/A	N/A	N/A
25	X22	0	0		0	4	0	0	1	1	0	0	2.31	N/A	N/A	N/A
26	X23	0	0		2	4	0	0	1	1	1	1	2.51	N/A	N/A	N/A
27	X24	0	0	Co	7	4	2	2	3	2	2	2	3.45	N/A	N/A	N/A
28	X25	0	0	Co	7	4	2	2	3	2	2	2	3.55	N/A	N/A	N/A
29																
30	Res. Used:	0			0	0	0	0	0	0	0	0				
31	Available:	5			14	14	5	5	10	5	5	5				
32																
33	Slack:				0	0	0	0	0	0	0	0	0	OBJ. FCTN:		
34	Totals:				0	0	0	0	0	0	0	0				
35	*Precedence Relationships:*															
36	*1) X1 before X2*					0										
37	*2) X7 before X4*					0										

Figure 5. Excel spreadsheet showing the Solver parameters for the fully constrained problem (initial scheduling stage).

completed before company scenarios are scheduled.

The constraints D36, D37, D38 and D39 ≤ 1 ensure that only one of the individual scenarios in a precedence relationship is scheduled at a time (stage). The cells contain the summation part of Equation 8.

Nonnegativity for slack variables is represented by the constraint E33:L33 ≥ 0. Negative slack variables means resource capacities have been exceeded, and this is not allowable.

The remaining constraints, E34 = E31, F34= F31, G34= G31, H34= H31, I34= I31, J34= J31, K34= K31, and L34= L31, ensures the resource "totals" equal the resources available.

4.5 Example Stage By Stage Model Implementation

Using the constraints from section 4.4.3 and the *Excel* worksheet format described in section 4.2, the implementation of the algorithm is demonstrated with a "walk through" of the first three stages of the fully constrained problem found in Table 34, Appendix C.

4.5.1 Initial Stage (Stage = 1, $t_1 = 0$):

Initialize all changing cells to zero. Ensure that all cell formulas are correct and properly referenced by the Solver tool. Start times, end times, and time remaining should display "N/A." Set current time equal to zero and $I = \{1, 2, 3, ..., 25\}$. Using the Solver "Options" button, check the "assume linear model" box. Click the "Solve" button to obtain the first solution.

The set of scenarios selected is X1, X5, X6, X8, and X23 ($SS_1 = \{1, 5, 6, 8, 23\}$). The unscheduled scenarios (SU_1) are $\{2, 3, 4, 7, 9, 10, ..., 22, 24, 25\}$ and the current set of scenarios (C_1) equals SS_1. The objective function value is eleven (figure 6). The start

times, end times and time remaining for each of these scenarios is automatically displayed in the respective cells. As discussed in section 4.2.8, "harden" the start and end time values by entering the same number shown in each cell from the keyboard. For example, all start times at this stage are zero because of the formulas used to compute

Microsoft Excel - FIG&SCHS.XLS

M33 =SUM(E33:L33)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1												Current Time:		0	Next:	2.12
2					*****Manned Module Resource Requirements*****											Time
3	Scen.#	Xij	Yij		M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
4	X1	1	0		4	0	1	1	3	1	0	0	2.12	0	2.12	2.12
5	X2	0	0		4	2	1	3	3	2	0	0	3.27	N/A	N/A	N/A
6	X3	0	0		4	0	0	0	2	1	0	0	2.19	N/A	N/A	N/A
7	X4	0	0		4	3	1	0	2	1	1	1	2.49	N/A	N/A	N/A
8	X5	1	0		4	2	0	1	1	1	1	0	2.39	0	2.39	2.39
9	X6	1	0		1	4	1	1	3	1	0	0	2.45	0	2.45	2.45
10	X7	0	0		2	4	1	1	3	1	0	0	2.47	N/A	N/A	N/A
11	X8	1	0		3	4	0	0	1	1	1	1	3.12	0	3.12	3.12
12	X9	0	0		0	4	0	0	1	1	0	0	2.1	N/A	N/A	N/A
13	X10	0	0	Co	7	4	2	2	3	3	2	2	3.38	N/A	N/A	N/A
14	X11	0	0	Co	7	4	2	2	3	2	2	2	3.47	N/A	N/A	N/A
15	X12	0	0		5	5	1	1	2	1	2	1	3.22	N/A	N/A	N/A
16	X13	0	0	Co	4	7	2	1	3	1	2	2	3.42	N/A	N/A	N/A
17	X14	0	0	Co	7	7	2	2	3	3	3	2	3.59	N/A	N/A	N/A
18	X15	0	0		4	1	1	1	3	1	0	0	2.41	N/A	N/A	N/A
19	X16	0	0		4	2	1	3	3	1	0	0	2.48	N/A	N/A	N/A
20	X17	0	0		4	3	0	0	2	2	1	1	3.3	N/A	N/A	N/A
21	X18	0	0		4	0	1	0	2	1	0	0	2.11	N/A	N/A	N/A
22	X19	0	0		4	1	0	1	1	1	0	0	2.36	N/A	N/A	N/A
23	X20	0	0		1	4	1	1	3	1	0	0	2.28	N/A	N/A	N/A
24	X21	0	0		2	4	1	1	3	1	0	0	2.24	N/A	N/A	N/A
25	X22	0	0		0	4	0	0	1	1	0	0	2.31	N/A	N/A	N/A
26	X23	1	0		2	4	0	0	1	1	1	1	2.51	0	2.51	2.51
27	X24	0	0	Co	7	4	2	2	3	2	2	2	3.45	N/A	N/A	N/A
28	X25	0	0	Co	7	4	2	2	3	2	2	2	3.55	N/A	N/A	N/A
29																
30	Res. Used:	5			14	14	2	3	9	5	3	2				
31	Available:	5			14	14	5	5	10	5	5	5				
32																
33	Slack:				0	0	3	2	1	0	2	3	11	OBJ. FCTN:		
34	Totals:				14	14	5	5	10	5	5	5				
35	*Precedence Relationships:*															
36	*1) X1 before X2*					1										

Figure 6. Excel spreadsheet showing stage 1 of the fully constrained model.

them. In each of the start time cells for the five scenarios, enter the *number* "zero" from the keyboard. In the end time cell for Scenario X1, enter the number 2.12; for Scenario X5, enter the number 2.39, and continue this for the other three scenarios. Note that these end times are the duration times for each scenario. Do <u>not</u> "harden" the *time remaining* values! They will be automatically updated at each scheduling stage until they reach zero. When they reach zero, then enter the text "N/A." The time of the next stage ($t_2 = \min_i \{f_i \mid i \in C_1\}$) is in the *Next* cell which shows a value of 2.12 (minimum remaining scenario duration). At time 2.12, the resources used by the completed scenario (X1) are "released," added to the slack resources from stage zero, and the model is resolved. Use the *Edit>Move or Copy Sheet* function to make a duplicate copy of stage one. This will be the starting point for the next stage. Note that SC_2 and CO_2 equal {1}and R_2 equals {5, 6, 8, 23}at the beginning of the next stage.

4.5.2 Second Stage (Stage = 2, t_2 = 2.12)

Rename the duplicate sheet for this stage. The author used "time = 2.12." Next, change the *Current Time* cell to 2.12. The values in the time remaining cells for the five scenarios immediately are updated to reflect the current time. The *Next* cell will have a value of zero because the minimum value in the time remaining column is now zero, the value of Scenario X1. "Harden" Scenario X1 next by entering a zero in its x_{ij} cell, a one in its y_{ij} cell, and "N/A" text in the start, end, and time remaining cells. The resources are also automatically updated to reflect a decrease in scenarios "used" and increases in

resources available (slack variables). Before solving the model at this stage, new constraints must be added to the Solver. First, the constraint B4 = 0 must be entered to ensure that this scenario (X1) is not scheduled again. Alternatively, the constraint B4 + C4 ≤ 1 will do the same thing. In this demonstration, manual changes were used to

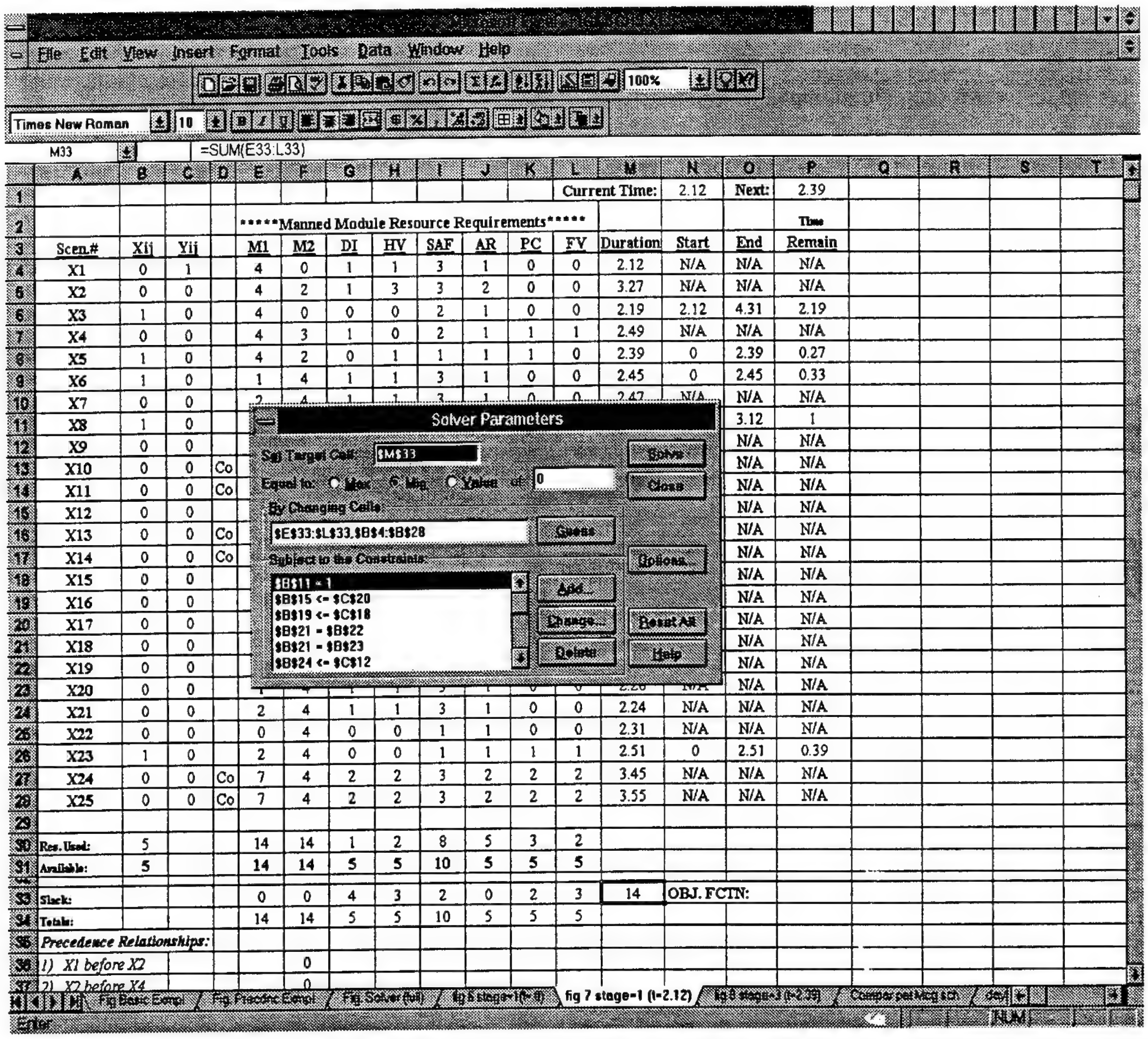


Figure 7. Excel spreadsheet showing stage 2 of the fully constrained model.

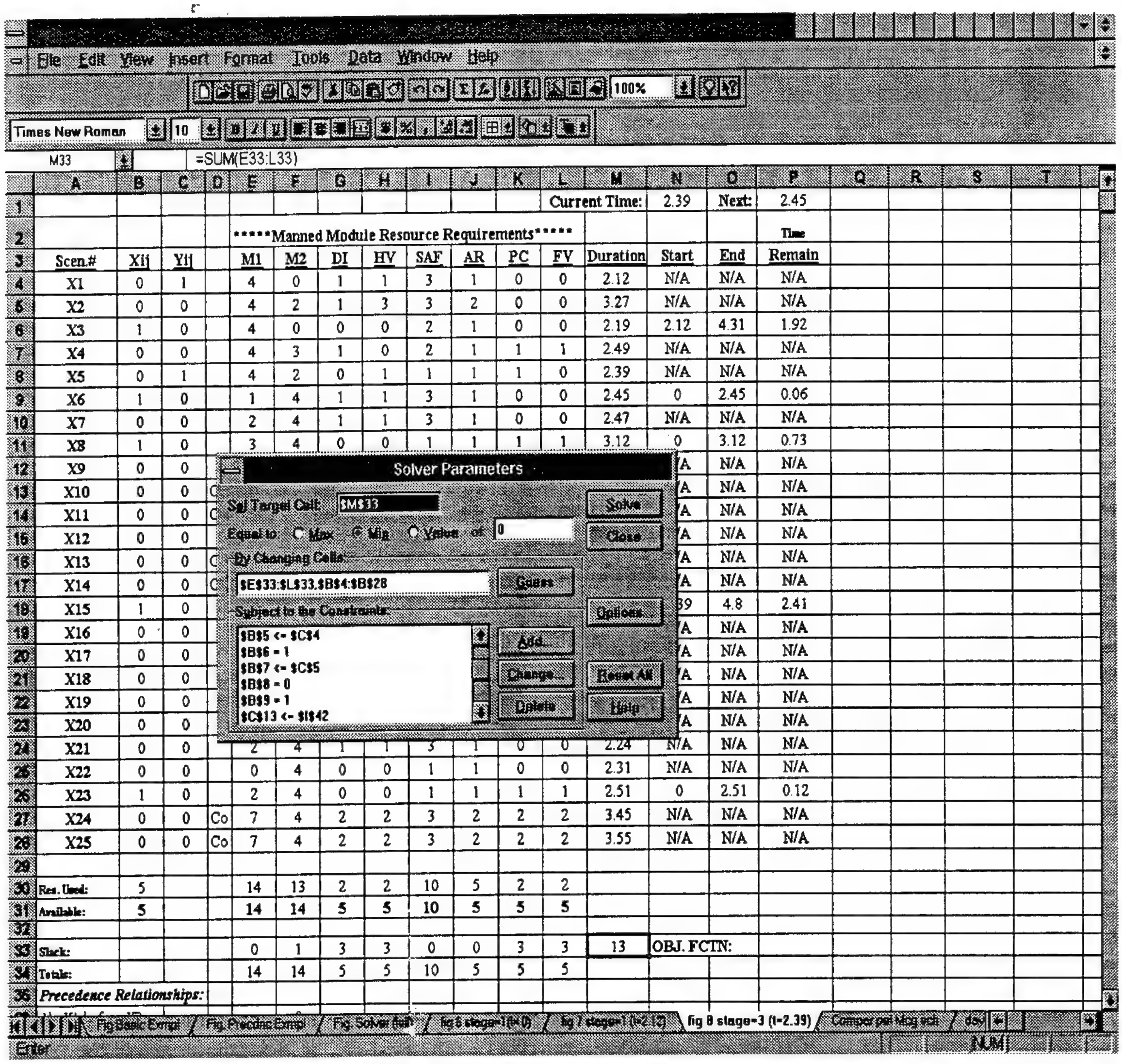
reduce the number of constraints. It prevents the Solver from changing its value and will remain in the Solver throughout the remainder of the planning horizon. Secondly, we must enter a "temporary" constraint which "forces" the Solver to schedule the ongoing scenarios again. This is done setting their x_{ij} cells equal to one. Thus, B8 = 1, B9 = 1, B11 = 1, and B26 = 1. Once the new constraints are added, click the "Solve" button.

A new scenario, X3, was selected for scheduling at the second stage, $t_2 = 2.12$ (SS_2 equals {3}). The objective function value was fourteen (figure 7). The *Next* cell is updated and shows a value of 2.39 ($t_3 = \min_i \{f_i \mid i \in C_2\}$). The unscheduled scenarios (SU_2) are {2, 4, 7, 9, 10, ..., 22, 24, 25} and the current set of scenarios equals the remaining set of scenarios from stage 1 plus the newly scheduled scenario X3 ($C_2 = R_2 + SS_2$ = {3, 5, 6, 8 ,23}). "Harden" the start and end times and use the *Edit>Move or Copy Sheet* function to make a duplicate copy of stage two. This will be the starting point for the next stage. Note that SC_3 equals {5}and CO_3 equals {1, 5}and R_3 equals {3, 6, 8, 23}at the beginning of the next stage.

4.5.3 Third Stage (Stage = 3, $t_3 = 2.39$)

Rename the duplicate sheet for this stage "time = 2.39." Change the *Current Time* cell to 2.39 and again the values in the time remaining cells for the five scenarios automatically are updated to reflect the current time. The *Next* cell will have a value of zero because the minimum value in the time remaining column is now zero, the value of Scenario X5. Update Scenario X5 next by entering a zero in its x_{ij} cell, a one in its y_{ij} cell,

and "N/A" text in the start, end, and time remaining cells. Again, the resources are updated to reflect a decrease in scenarios "used" and increases in resources available



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1												Current Time:		2.39	Next:	2.45
2					*****Manned Module Resource Requirements*****											Time
3	Scen.#	Xij	Yij		M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
4	X1	0	1		4	0	1	1	3	1	0	0	2.12	N/A	N/A	N/A
5	X2	0	0		4	2	1	3	3	2	0	0	3.27	N/A	N/A	N/A
6	X3	1	0		4	0	0	0	2	1	0	0	2.19	2.12	4.31	1.92
7	X4	0	0		4	3	1	0	2	1	1	1	2.49	N/A	N/A	N/A
8	X5	0	1		4	2	0	1	1	1	1	0	2.39	N/A	N/A	N/A
9	X6	1	0		1	4	1	1	3	1	0	0	2.45	0	2.45	0.06
10	X7	0	0		2	4	1	1	3	1	0	0	2.47	N/A	N/A	N/A
11	X8	1	0		3	4	0	0	1	1	1	1	3.12	0	3.12	0.73
12	X9	0	0											A	N/A	N/A
13	X10	0	0	C										A	N/A	N/A
14	X11	0	0	C										A	N/A	N/A
15	X12	0	0											A	N/A	N/A
16	X13	0	0	C										A	N/A	N/A
17	X14	0	0	C										A	N/A	N/A
18	X15	1	0											39	4.8	2.41
19	X16	0	0											A	N/A	N/A
20	X17	0	0											A	N/A	N/A
21	X18	0	0											A	N/A	N/A
22	X19	0	0											A	N/A	N/A
23	X20	0	0											A	N/A	N/A
24	X21	0	0		2	4	1	1	3	1	0	0	2.24	N/A	N/A	N/A
25	X22	0	0		0	4	0	0	1	1	0	0	2.31	N/A	N/A	N/A
26	X23	1	0		2	4	0	0	1	1	1	1	2.51	0	2.51	0.12
27	X24	0	0	Co	7	4	2	2	3	2	2	2	3.45	N/A	N/A	N/A
28	X25	0	0	Co	7	4	2	2	3	2	2	2	3.55	N/A	N/A	N/A
29																
30	Res. Used:	5			14	13	2	2	10	5	2	2				
31	Available:	5			14	14	5	5	10	5	5	5				
32																
33	Slack:				0	1	3	3	0	0	3	3	13	OBJ. FCTN:		
34	Totals:				14	14	5	5	10	5	5	5				
35	*Precedence Relationships:*															

Figure 8. Excel spreadsheet showing stage 3 of the fully constrained model.

(slack variables). Before solving the model at this stage, new constraints must again be added to the Solver. First, the constraint B8 = 0 must be entered to ensure that this

scenario (X5) is not scheduled again. Secondly, we must enter a "temporary" constraint which "forces" the Solver to reschedule the most recently selected (and ongoing) scenario again. Thus, set B6 = 1 (Scenario X3). The other ongoing scenario constraints remain exactly the same in the Solver as from the previous stage. Once the new constraint is added, click the "Solve" button.

A new scenario, X15, was selected for scheduling at stage 2.39 (SS_3 equals {15}). The objective function value was thirteen (figure 8). The *Next* cell is updated and shows a value of 2.45 ($t_4 = \min_i \{f_i \mid i \in C_3\}$). The unscheduled scenarios (SU_3) are {2, 4, 7, 9, 10, ..., 14, 16, ..., 22, 24, 25} and the current set of scenarios equals the remaining set of scenarios from stage 2 plus the newly scheduled scenario X15 ($C_3 = R_3 + SS_3$ = {3, 6, 8, 15, 23}). "Harden" the start and end times and use the *Edit>Move or Copy Sheet* function to make a duplicate copy of stage two. This will be the starting point for the next stage. Note that SC_4 equals {6}and CO_4 equals {1, 5, 6}and R_4 equals {3, 8, 15, 23}at the beginning of the next stage.

4.5.4 Remaining Stages

This iterative process is continued until all scenarios are scheduled. At some stages, no additional scenarios are scheduled and, at other stages, multiple scenarios are scheduled. Table 34, Appendix C, shows the final results of this stage by stage scheduling process. Note that all precedence constraints were satisfied.

4.6 Summary of Models Used

Three models of increasing complexity were used to test the TSSP algorithm. For each model, the iterative procedure discussed in section 4.5 was used to generate a CCTT schedule. The first model (basic model) used to test the algorithm considered only resource capacities as problem constraints. Stage by stage output is shown for this model in Tables 8 through 32, Appendix A. The second model (partially constrained model) considered resource capacities, precedence relationships between individual scenarios, and simultaneous scheduling of three scenarios as constraints and is shown in Table 33, Appendix B. The third model (fully constrained model) included all the constraints of the second model plus a precedence constraint between individual scenarios and a group of scenarios. This model was discussed in the previous section and is shown in Table 34, Appendix C.

For each of the models, a final CCTT schedule was developed (figures 9, 10, and 11). To produce these figures, the author used results from the final scheduling stages to manually input the scenarios on a separate *Excel* worksheet. Slack resources at each scheduling stage are shown on each of CCTT schedules.

CHAPTER 5

COMPUTATIONAL EVALUATION AND RESULTS

The algorithm developed in this thesis produced schedules that were both feasible and effective. In each of the three models tested, *all* resource capacity, individual and group precedence relationships, and simultaneous scenario constraints were satisfied. The schedules generated for each model were developed using the resource types and capacities listed in section 4.2.4 where the M1, M2, SAF, AARs resources were actual site requirements and the other resources were increased for algorithm implementation. Also, recall from Chapter 4 that there are three model types:

(a) *basic model* - only resource capacities were used as problem constraints,

(b) *partially constrained model* - resource capacities, requirement for three simultaneous exercises (X18, X19, X20), and five individual precedence relationships (X1 before X2, X2 before X4, X9 before X21, X15 before X16, and X17 before X12) were used as problem constraints, and

(c) *fully constrained model* - part (b) plus the requirement that all platoon scenarios be completed before scheduling company scenarios.

Resource utilizations obtained were "good" for each resource type in each of the models (see Table 4). Resource utilization was computed by subtracting the "idle"

(unused) resource percentage from 100%. The idle percentage was calculated by dividing the total number of unused hours for a resource by the total available resource hours and multiplying this this result by 100 (%). For example, for the M1 resource in the basic model, idle percentage is computed as:

Total M1 resource hours available = 22 hours × 14 M1 modules

= 308 available hours

Total hours resource is idle = (2.41 hours × 0 M1's) + (.1 hours × 0 M1's) + (.76 hours × 2 M1's) + ... + (.8 hours × 7 M1's) = 25.9 hours

Percent resource is idle = 25.9/308 = .08 × 100% = 8%

Percent resource is used = 100% - 8% = 92%.

A brief discussion of each model output follows.

5.1 Basic Model (Resource Constraints Only)

The final results of the basic model are on shown in Table 32, Appendix A. For this model only, the stage by stage scheduling process is also shown in Tables 8 through 32, Appendix A. Total schedule duration for all twenty-five scenarios is twenty-two hours, meaning that the last scenario scheduled ended twenty-two hours after the first scenarios were scheduled. Figure 9 shows what the CCTT schedule would look like when the final results are placed in a usable "schedule" format. Slack resources are

Time	Set # 1	Set # 2	Set # 3	Set # 4	Set # 5	M1	M2	DI	HV	SAF	AR	PC	FV
0	Scen. # 15	Scen. # 23	Scen. # 2	Scen. # 13	Not Used	0	0	1	0	0	0	2	2
2.41	Scen. # 1					0	1	1	0	0	0	2	2
2.51		Scen. # 9				2	1	1	0	0	0	3	3
3.27			Scen. # 16		Not Used	2	1	1	0	0	1	3	3
3.42				Scen. # 4	Scen. # 22	2	1	2	1	0	0	4	4
4.53	Scen. # 18					2	1	2	2	1	0	4	4
4.61		Not Used				2	5	2	2	2	1	4	4
5.73		Scen. # 7			Not Used	0	5	1	1	0	1	4	4
5.75			Scen. # 17			0	4	2	4	1	0	3	3
5.91				Scen. # 21		2	3	2	3	0	0	4	4
6.64	Scen. # 5					2	1	3	2	1	0	3	4
8.15				Scen. # 6		3	1	3	2	1	0	3	4
8.2		Scen. # 12				0	0	3	2	2	0	1	3
9.03	Scen. # 19					0	1	3	2	2	0	2	3
9.05			Scen. # 8			1	0	3	2	3	1	2	3
10.6				Scen. # 20		1	0	3	2	3	1	2	3
11.4	Scen. # 10	Not Used				3	2	2	2	3	0	2	2
12.2			Scen. # 3			2	6	2	2	2	0	3	3
12.9				Not Used		3	10	3	3	5	1	3	3
14.4			Scen. # 11			0	6	1	1	4	0	1	1
14.8	Scen. # 14					0	3	1	1	4	0	0	1
17.9			Scen. # 24			0	3	1	1	4	0	0	1
18.4	Scen. # 25					0	6	1	1	4	1	1	1
21.4			Not Used			7	10	3	3	7	3	3	3
22	Not Used	Not Used		Not Used	Not Used	Exhausted all scenarios							

Amount of unused resources (slack): columns M1 through FV.

Note: Time column represents the *start* times for each scenario.

Figure 9. CCTT schedule for basic model of Table 32

shown on this table at each scheduling stage to let the CCTT manager know how much flexibility he or she has (and exactly where) to modify and/or supplement units that may be training at that particular stage or offer "some" resources to unforecasted requests. At only one point during the scheduling process was the CCTT system capable of conducting five simultaneous exercises (stage times 3.42 to 4.61). Resource utilization for each resource type in this model is shown in Table 4. The most important resources (those that can stop unit training from taking place) such as M1, M2, DI, SAF,and AAR,

Table 4

Comparison of Resource Utilization for the Basic, Partially Constrained, and Fully Constrained Models

	Resource Types							
	M1	M2	DI	HV	SAF	AR	PC	FV
Basic Model:								
Total Avail. Resource Hours.	308	308	110	110	220	110	110	110
Total Hours Resource Idle	25.9	70.3	40.4	32.2	56.3	9.94	44.1	53.3
Idle Resource %	8.42	22.8	36.7	29.3	25.6	9.04	40.1	48.5
Resource Utilization %	91.6	77.2	63.3	70.7	74.4	91	59.9	51.5
Partially Constrained Model:								
Total Avail. Resource Hours.	333	333	119	119	238	119	119	119
Total Hours Resource Idle	51.8	96.4	49.6	41.6	74.6	19.2	53.5	62.7
Idle Resource %	15.5	28.9	41.7	34.9	31.3	16.1	44.9	52.7
Resource Utilization %	84.5	71.1	58.3	65.1	68.7	83.9	55.1	47.3
Fully Constrained Model:								
Total Avail. Resource Hours.	326	326	117	117	233	117	117	117
Total Hours Resource Idle	45.6	89.6	47.3	39.1	70	16.9	51	60.2
Idle Resource %	14	27.4	40.6	33.5	30	14.5	43.8	51.7
Resource Utilization %	86	72.6	59.4	66.5	70	85.5	56.2	48.3

show utilization percentages of 91.6%, 77.2%, 63.3%, 74.4%, and 91% respectively for the basic model. These specific modules were considered the most important resources because they either directly affect a unit's ability to train on essential warfighting skills (e. g., tank platoons *require* M1A1/A2 tanks to accomplish their training objectives and could simulate a command vehicle (HMMWV) using BLUESAF if necessary) or they affect the ability to exercise scenario on the CCTT system (e. g., exceeding SAF workstation constraints will result in no training being accomplished regardless of training objectives). Although there is no established standard for "acceptable" or "desirable" resource utilization percentages, the author believes these percentages would certainly be satisfactory to CCTT managers.

5.2 Partially Constrained Model (Precedence Relationships Between Individual Scenarios and Requirement for Three Simultaneously Scheduled Scenarios)

The final results of the partially constrained model are shown in Table 33, Appendix B. All individual precedence relationships and simultaneous scheduling requirements were satisfied. Total schedule duration for all twenty-five scenarios is 23.81 hours. This is an increase in duration of 1.81 hours over the basic model. This is not surprising since one would expect the schedule to "lengthen" when more scheduling constraints (considerations) are added. Figure 10 shows the CCTT schedule for this model and the corresponding slack variables at each scheduling stage. In this model, conducting five simultaneous exercises did not occur at any point during the schedule.

Time	Set # 1	Set # 2	Set # 3	Set # 4	Set # 5	M1	M2	DI	HV	SAF	AR	PC	FV
0	Scen. # 5	Scen. # 6	Scen. # 7	Scen. # 24	Not Used	0	0	1	0	0	0	2	3
2.39	Not Used					4	2	1	1	1	1	3	3
2.45	Scen. # 15	Scen. # 9				1	1	1	1	0	0	3	3
2.47			Scen. # 8			0	1	2	2	2	0	2	2
3.45				Scen. # 11		0	1	2	2	2	0	2	2
4.55		Scen. # 22				0	1	2	2	2	0	2	2
4.86	Scen. # 16					0	0	2	0	2	0	2	2
5.59			Scen. # 23			1	0	2	0	2	0	2	2
6.86		Not Used				1	4	2	0	3	1	2	2
6.92		Scen. # 1		Scen. # 13		0	1	1	0	0	1	2	2
7.34	Scen. # 17					0	0	2	3	1	0	1	1
8.1			Not Used			2	4	2	3	2	1	2	2
9.04		Scen. # 3	Scen. # 21			0	0	2	3	0	0	2	2
10.34				Not Used		4	7	4	4	3	1	4	4
10.64	Scen. # 14					1	3	2	2	2	0	2	3
11.23		Not Used				5	3	2	2	4	1	2	3
11.28		Scen. # 25	Not Used			0	3	1	1	4	0	0	1
14.23	Scen. # 10					0	6	1	1	4	0	1	1
14.83		Scen. # 12	Not Used	Not Used		2	5	2	2	5	1	1	2
17.61	Scen. # 18		Scen. # 19	Scen. # 20		0	4	2	2	2	1	3	4
18.05		Scen. # 2				1	7	2	0	1	0	5	5
19.72	Not Used					1	7	2	0	1	0	5	5
19.89				Not Used		6	11	4	1	6	2	5	5
19.97	Not Used		Not Used			10	12	4	2	7	3	5	5
21.32	Scen. # 4	Not Used				10	11	4	5	8	4	4	4
23.81	Not Used		Not Used	Not Used	Not Used	Exhausted all scenarios							

Amount of unused resources (slack): M1 M2 DI HV SAF AR PC FV

Note: Time column represents the *start* times for each scenario.

Figure 10. CCTT schedule for partially constrained model of Table 33.

This was probably attributed to the additional constraint requiring Scenarios X18, X19, and X20 to be scheduled at the same stage during the planning horizon. Resource utilization for each resource type in this model is shown in Table 4. The resources, M1, M2, DI, SAF, and AR, show utilization percentages of 84.5%, 71.1%, 58.3%, 68.7%, and 83.9% respectively. Utilization dropped between 5% and 8% for each of the resources but remain "good." Again, by adding constraints one would expect the problem solution to get worse, including reductions in resource utilization.

5.3 Fully Constrained Model (Precedence Relationships Between Individual Scenarios, Between Individual and Group Scenarios, and Requirement for Three Simultaneously Scheduled Scenarios)

The final results of the fully constrained model is on shown in Table 34, Appendix C. All individual and group precedence relationships and simultaneous scheduling requirements were satisfied. The additional constraint to this problem from the one in the previous section was the requirement for all platoon scenarios to be completed before scheduling any company scenarios. Total schedule duration for all twenty-five scenarios is 23.32 hours. This is a *decrease* in total duration of approximately one half hour over the partially constrained model. This is somewhat surprising since one would expect the schedule to "lengthen," as previously mentioned, when more scheduling constraints (considerations) are added. However, it is known that

Time	Set # 1	Set # 2	Set # 3	Set # 4	Set # 5
0	Scen. # 1	Scen. # 5	Scen. # 6	Scen. # 8	Scen. # 23
2.12	Scen. # 3				
2.39		Scen. # 15			
2.45			Scen. # 22		
2.51					Scen. # 7
3.12				Scen. # 9	
4.31	Not Used				
4.76			Scen. # 2		
4.8		Not Used			
4.98					Scen. #17
5.22				Scen. #21	
7.46		Not Used		Not Used	
8.03		Scen. #4	Scen. #16		
8.28					Scen. #12
10.51	Not Used		Not Used		
10.52	Scen. #18	Scen. #19	Scen. #20		
11.5					Not Used
12.63	Not Used				
12.8	Not Used		Not Used		
12.88	Scen. #14	Scen. #25			
16.43		Scen. #24			
16.47	Scen. #10				
19.85	Scen. #11				
19.88		Scen. #13			
23.3		Not Used			
23.32	Not Used	Not Used	Not Used	Not Used	Not Used

Note: Time column represents the *start* times for each scenario.

Amount of unused resources:

M1	M2	DI	HV	SAF	AR	PC	FV
0	0	3	2	1	0	2	3
0	0	4	3	2	0	2	3
0	1	3	3	0	0	3	3
1	1	4	4	2	0	3	3
1	1	3	3	0	0	4	4
4	1	3	3	0	0	5	5
8	1	3	3	2	1	5	5
4	3	2	0	0	0	5	5
8	4	3	1	3	1	5	5
6	5	4	2	4	0	4	4
4	5	3	1	2	0	4	4
6	9	4	2	5	1	4	4
2	6	3	2	3	1	3	3
1	4	2	1	3	2	2	3
5	6	3	4	6	3	2	3
0	4	2	2	2	1	3	4
5	9	3	3	4	2	5	5
9	9	4	3	6	3	5	5
10	13	5	4	9	4	5	5
0	3	1	1	4	0	0	1
0	3	1	1	4	0	0	1
0	6	1	1	4	0	1	1
0	6	1	1	4	1	1	1
3	3	1	2	4	2	1	1
7	10	3	3	7	3	3	3

Exhausted all scenarios

Figure 11. CCTT schedule for fully constrained model of Table 34.

delaying a job (leaving some resources idle) will sometimes result in a shorter schedule. In this case, scheduling the platoons before scheduling a company scenario has a lower resource utilization at the first decision stage but an overall higher system utilzation. Since all platoon scenario durations are smaller than company scenario durations, the queueing theory principle that "shortest jobs first" produce the best overall system "flow time" may explain the reduction in duration. Figure 11 shows the CCTT schedule for this model and the corresponding slack variables at each scheduling stage. In this model, conducting five simultaneous exercises occurred for 4.31 hours during the schedule (stages zero to 4.31). Resource utilization for each resource type in this model is shown on Table 4. The resources, M1, M2, DI, SAF, and AR, show utilization percentages of 86%, 72.6%, 59.4%, 70%, and 85.5% respectively. Utilization increased slightly (1% or 2%) for each of the resource types.

5.4 Comparison of the TSSP Scheduling Heuristic to McGinnis and Phelan's (1996) Hybrid Expert System

Table 5 shows the sixteen scenarios and their respective resource requirements that were used in testing the application of McGinnis and Phelan's (1996) hybrid expert system algorithm. Resource requirements for each scenario were derived from the standard resources of Table 3. The information in this table appeared in McGinnis and Phelan's (1996) technical report.

Recall that REDSAF was the only resource constraint used by McGinnis and Phelan in obtaining a CCTT schedule. The schedule produced by their expert system is shown on the next page (figure 12). This schedule was feasible in terms of REDSAF but violated at least one other resource type at each scheduling stage during the planning

Table 5

Sample Scenarios Taken From McGinnis and Phelan's (1996) Technical Report

Scen. #	Unit Size	Unit Type	Trg Context	Exercise Type	Resource Requirements M1	M2	DI	HV	SAF	AR	PC	FV	Scen. Duration
X1	PLT	INF	Co	MTC	0	4	2	0	2	1	0	0	2 hrs.
X2	PLT	INF	Co	MTC	0	4	2	0	2	1	0	0	2 hrs.
X3	PLT	INF	Co	MTC	0	4	2	0	2	1	0	0	2 hrs.
X4	PLT	AR	Co	MTC	4	0	0	0	2	1	0	0	2 hrs.
X5	PLT	AR	Co	ATK	2	4	0	0	2	1	0	0	2 hrs.
X6	PLT	AR	Co	ATK	2	4	0	0	2	1	0	0	2 hrs.
X7	PLT	INF	Co	ATK	0	4	2	0	2	1	0	0	2 hrs.
X8	PLT	INF	Plt	MTC	0	4	2	0	1	1	0	0	2 hrs.
X9	PLT	AR	Plt	MTC	4	0	0	0	1	1	0	0	2 hrs.
X10	PLT	AR	Plt	ATK	4	0	0	0	1	1	0	0	2 hrs.
X11	PLT	INF	Plt	ATK	0	4	2	0	1	2	1	1	2 hrs.
X12	CO	INF	Co	ATK	4	10	4	1	2	2	1	1	3 hrs.
X13	CO	INF	Co	ATK	4	10	4	1	2	2	1	1	3 hrs.
X14	CO	AR	Co	ATK	10	4	2	1	2	2	1	1	3 hrs.
X15	CO	AR	Co	ATK	10	4	2	1	2	2	1	1	3 hrs.
X16	BN	MIX	Bn	DEF	14	14	6	5	10	5	5	5	6 hrs.
Available Resources					*14*	*14*	*6*	*5*	*10*	*5*	*5*	*5*	

horizon. The amount of resources used by McGinnis and Phelan's schedule are shown on the schedule. It is obvious that resource capacities were exceeded. For comparison of scheduling efficiency, the TSSP scheduling heuristic was applied to the McGinnis and Phelan problem using s "SAF workstation only" constraint (all other resources were "unlimited"). Both approaches required the battalion scenario to be scheduled last. The

Amount of USED resources:

Hour	Set # 1	Set # 2	Set # 3	Set # 4	Set # 5	MI	M2	DI	HV	SA	AR	PC	FV
1	Scen. # 1	Scen. # 4	Scen. # 2	Scen. #12	Scen. # 9	12	18	8	1	9	6	1	1
2				(CO)		12	18	8	1	9	6	1	1
3	Scen. # 5	Scen. # 7	Scen. #10		Scen. #11	10	22	8	1	8	7	1	1
4				Scen. # 8		6	16	6	0	7	6	1	1
5	Scen. #15	Scen. #14	Scen. #13		Not Used	24	22	10	3	7	7	3	3
6	(CO)	(CO)	(CO)	Scen. # 6	Scen. # 3	26	26	10	3	10	8	3	3
7						26	26	10	3	10	8	3	3
8	Scen. #16	Not Used	Not Used	Not Used	Not Used	14	14	3	2	10	5	2	4
9	(BN)												
10													
11													
12													
13													
14	Not Used	Not Used	Not Used	Not Used	Not Used								

Exhausted all scenarios. Shaded areas represent violations of resource capacities.

Note: Time column represents the *start* times for each scenario. Box size and duration times are not linearly related.

Figure 12. CCTT schedule generated by hybrid expert system (McGinnis and Phelan, 1996)

Amount of USED resources:

Time	Set # 1	Set # 2	Set # 3	Set # 4	Set # 5	MI	M2	DI	HV	SA	AR	PC	FV
0	Scen. # 1	Scen. # 2	Scen. # 3	Scen. # 4	Scen. # 5	6	16	6	0	10	5	0	0
1													
2	Scen. # 6	Scen. # 7	Scen. #12	Scen. #14	Scen. #15	26	26	10	3	10	8	3	3
3			(CO)	(CO)	(CO)								
4	Scen. # 8	Scen. #13				28	32	14	4	9	9	4	4
5		(CO)	Scen. # 9	Scen. #10	Scen. #11	12	18	8	1	6	7	2	2
6	Not Used					12	14	6	1	5	6	2	2
7	Scen. #16	Not Used	Not Used	Not Used	Not Used	14	14	3	2	10	5	2	4
8	(BN)												
9													
10													
11													
12													
13	Not Used	Not Used	Not Used	Not Used	Not Used								

Exhausted all scenarios. Shaded areas represent violations of resource capacities.

Note: Time column represents the *start* times for each scenario. Box size and duration times are not linearly related.

Figure 13. CCTT schedule derived from TSSP Heuristic applied to McGinnis and Phelan (1996) problem.

Time	Set # 1	Set # 2	Set # 3	Set # 4	Set # 5	M1	M2	DI	HV	SAF	AR	PC	FV
0	**Scen. # 1**	**Scen. # 11**	**Scen. # 14 (CO)**	**Scen. # 4**	**Not Used**	0	2	0	4	3	0	3	3
1													
2	**Scen. # 13 (CO)**	**Not Used**		**Not Used**		0	0	0	3	6	1	3	3
3			**Scen. # 15 (CO)**			0	0	0	3	6	1	3	3
4													
5	**Scen. # 12 (CO)**	**Not Used**		**Not Used**		0	0	0	3	6	1	3	3
6		**Scen. # 7**	**Scen. # 8**	**Scen. # 9**		2	0	0	4	4	0	4	4
7													
8	**Scen. # 3**	**Scen. # 5**	**Scen. # 6**	**Not Used**		10	2	4	5	4	2	5	5
9													
10	**Scen. # 2**	**Scen. # 8**	**Not Used**			14	6	2	5	7	3	5	5
11													
12	**Scen. # 16 (BN)**	**Not Used**				0	0	3	3	0	0	3	1
13													
14													
15													
16													
17													
18	**Not Used**	**Not Used**	**Not Used**	**Not Used**	**Not Used**								

Amount of unused resources (slack): columns M1–FV above.

Exhausted all scenarios

Note: Time column represents the <u>*start*</u> times for each scenario. Box size and duration times are <u>not</u> linearly related.

Figure 14. CCTT schedule derived from Table 36 (all resource constraints).

final results using the TSSP scheduling heuristic are shown in Appendix D. The total schedule duration of thirteen hours produced by the TSSP algorithm (figure 13) was exactly the same as that produced by the hybrid expert system approach. Slack variables show that some resources were exceeded, but they are comparable to the results generated by the hybrid expert system approach.

Next, the author used the same scenarios to solve the problem while satisfying all the resource capacity constraints. Resource capacities used were the same as those discussed in section 4.2.4 with one exception, DI was increased from five to six because each company scenario required four DI modules and no other scenario required only one DI module. Without increasing this resource, only one company (and no other scenario) could be scheduled at any given stage. This was considered unrealistic for practical use of the CCTT system. Essentially, the actual site configuration of three DI

Table 6

Resource Utilization Percentages Generated by the TSSP Scheduling Heuristic Using McGinnis and Phelan (1996) Scenarios (Satisfying All Resource Constraints)

	Resource Types							
	M1	M2	DI	HV	SAF	AR	PC	FV
Total Avail. Resource Hours	252	252	108	90	180	90	90	90
Total Hours Resource Idle	52	20	12	48	60	14	46	46
Idle Resource %	20.6	7.94	11.1	53.3	33.3	15.6	51.1	51.1
Resource Utilization %	79.4	92.1	88.9	46.7	66.7	84.4	48.9	48.9

modules was doubled. Final results and the CCTT schedule are shown in Appendix E. Total schedule duration increased from thirteen hours to eighteen hours (see figure 14). At no time during the scheduling process was the CCTT system capable of conducting five simultaneous exercises. Resource utilization for this problem was very good as indicated in Table 6.

5.5 Consideration of a Two Day Planning Horizon

McGinnis and Phelan used sixteen scenarios that they were able to schedule in approximately thirteen hours. In order to ensure feasibility for all resource types, their duration is extended to eighteen hours. For the basic test problem with twenty-five scenarios,the duration approaches twenty-four hours depending on precedence constraints used. Can the TSSP heuristic be modified to permit effective scheduling on successive training days? A modification is tested on the twenty-five scenario problem.

Since the schedule durations were long (approaching 24 hours each), a "cut-off" time of twelve hours was used and the algorithm applied to the unscheduled scenarios for both the partially constrained and fully constrained models. Scenarios that began prior to the twelve-hour stage were allowed to finish but no other scenario would be scheduled after the twelve hour stage.

The fully constrained model was easy to decompose because all of the company scenarios started at stage 12.88 (figure 11). Thus, the schedule remains exactly the same

with Scenarios X14 and X25 being scheduled first thing the next day. Resource utilization and total schedule duration remain the same as those in the single day schedule.

The partially constrained model would change however. Scenario X25 would be the last scenario scheduled on day one; it began at 11.28 and ended at 14.83. As a result of this, seven scenarios would have to be scheduled for the next day (X2, X4, X10, X12, X18, X19, and X20). Initializing all resources to their original capacities and scheduling the seven scenarios was accomplished in the same manner discussed in Chapter 4. Final results for day one and two are shown in Appendix F

Table 7

Comparison of Resource Utilization Percentages for the Partially Constrained Model Using a Two Day Planning Horizon

	Resource Types							
	M1	M2	DI	HV	SAF	AR	PC	FV
Day #1 Partially Constrained Model:								
Total Avail. Resource Hours	208	208	74.2	74.2	148	74.2	74.2	74.2
Total Hours Resource Idle	9.71	25.8	25	21.1	29.9	3.63	24.3	30.3
Idle Resource %	4.68	12.4	33.7	28.4	20.2	4.9	32.7	40.8
Resource Utilization %	95.3	87.6	66.3	71.6	79.8	95.1	67.3	59.2
Day #2 Partially Constrained Model:								
Total Avail. Resource Hours	113	113	40.2	40.2	80.4	40.2	40.2	40.2
Total Hours Resource Idle	29.6	57.5	20.1	15.8	35.6	11.1	24.5	27.7
Idle Resource %	26.3	51	49.9	39.2	44.3	27.5	61	69
Resource Utilization %	73.7	49	50.1	60.8	55.7	72.5	39	31
Combined Totals Over a Two Day Period:								
Total Avail. Resource Hours	320	320	114	114	229	114	114	114
Total Hours Resource Idle	39.3	83.3	45.1	36.9	65.6	14.7	48.8	58
Idle Resource %	12.3	26	39.4	32.2	28.7	12.8	42.7	50.7
Resource Utilization %	87.7	74	60.6	67.8	71.3	87.2	57.3	49.3

The combined two day schedule duration using this approach is 22.87 hours (14.83 hours (day 1) + 8.04 hours (day 2)), almost an hour shorter than the single day schedule. Table 7 shows the daily resource utilization percentages and the combined utilization percentages of the two day schedule. The resource utilization of the two day schedule is slightly better than the single day schedule. Increases of between 2% and 4% were achieved for all resource types using the two day schedule. The two day CCTT schedules are shown on the next page, figures 15 and 16.

It appears that the TSSP heuristic can be used effectively for multiple day scheduling of training scenarios. The only remaining question is when to break the day: based on the start times or on the finish times? Whatever the criterion, the TSSP heuristic can be used to develop an effective schedule.

Amount of unused resources:

Time	*Set # 1*	*Set # 2*	*Set # 3*	*Set # 4*	*Set # 5*	M1	M2	DI	HV	SA	AR	PC	FV
0	**Scen. # 5**	**Scen. # 6**	**Scen. # 7**	**Scen. #24**	**Not Used**	0	0	1	0	0	0	2	3
2.39	**Not Used**					4	2	1	1	1	1	3	3
2.45	**Scen. #15**	**Scen. # 9**				1	1	1	1	0	0	3	3
2.47			**Scen. # 8**			0	1	2	2	2	0	2	2
3.45				**Scen. #11**		0	1	2	2	2	0	2	2
4.55		**Scen. #22**				0	1	2	2	2	0	2	2
4.86	**Scen. #16**					0	0	2	0	2	0	2	2
5.59			**Scen. #23**			1	0	2	0	2	0	2	2
6.86		**Not Used**				1	4	2	0	3	1	2	2
6.92		**Scen. # 1**		**Scen. #13**		0	1	1	0	0	1	2	2
7.34	**Scen. #17**					0	0	2	3	1	0	1	1
8.1			**Not Used**			2	4	2	3	2	1	2	2
9.04		**Scen. # 3**	**Scen. #21**			0	0	2	3	0	0	2	2
10.3				**Not Used**		4	7	4	4	3	1	4	4
10.6	**Scen. #14**					1	3	2	2	2	0	2	3
11.2		**Not Used**				5	3	2	2	4	1	2	3
11.3		**Scen. #25**	**Not Used**			0	3	1	1	4	0	0	1
14.2	**Not Used**					7	10	3	3	7	3	3	3
14.8	**Not Used**	**Not Used**	**Not Used**	**Not Used**	**Not Used**	End	Day #1						

Note: Time column represents the *start* times for each scenario. Box size and duration times are not linearly related.

Figure 15. CCTT schedule for partially constrained model (Day 1) of Table 37.

Amount of unused resources:

Time	*Set # 1*	*Set # 2*	*Set # 3*	*Set # 4*	*Set # 5*	M1	M2	DI	HV	SA	AR	PC	FV
0	**Scen. #18**	**Scen. #20**	**Scen. #19**	**Scen. #12**	**Not Used**	0	4	2	2	2	1	3	4
2.11	**Not Used**					4	4	3	2	4	2	3	4
2.28	**Scen. # 2**	**Not Used**				1	6	3	0	4	1	3	4
2.36			**Not Used**			5	7	3	1	5	2	3	4
3.22		**Scen. #10**		**Not Used**		3	8	2	0	4	0	3	3
5.55	**Scen. # 4**					3	7	2	3	5	1	2	2
6.6		**Not Used**				10	11	4	5	8	4	4	4
8.04	**Not Used**	**Not Used**	**Not Used**	**Not Used**	**Not Used**	Exhausted all scenarios							

Note: Time column represents the *start* times for each scenario. Box size and duration times are not linearly related.

Figure 16. CCTT schedule for partially constrained model (Day 2) of Table 38.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

The algorithm developed in this thesis produced training schedules that were feasible, efficient, and practical. Feasibility was maintained from start to end without requiring any "repair" heuristics, as contrasted with work of McGinnis and Phelan. Although improvement heuristics could be developed to enhance the schedule results, it was beyond the scope of this research. The effectiveness of the algorithm was illustrated in the resource utilization percentages for each of the three models tested. With respect to schedule duration, it compared quite favorably with the hybrid expert system approach used by McGinnis and Phelan given the same scenarios and resource constraints. From a practical standpoint, CCTT managers can obtain a usable schedule where the degree of flexibility for increasing/decreasing/modifying the schedule at scenario start or end times is shown at each stage in the way of slack variables. If a unit leader wishes to add simulators to his or her training event, the CCTT manager can readily inform them of whether or not the request can be met. Theoretically, additional resources can be added to scenarios (if needed) at any given scheduling stage when positive slack variables are shown on the schedule at that particular stage.

6.2 Research Contributions

Several research contributions (benefits) resulted from the development of the TSSP algorithm.

One contribution this research makes is the mathematical formulation of the CCTT problem that includes all realistic constraints, unlike the formulation of McGinnis and Phelan. Solving this multi-stage decision problem by dynamically applying a zero-one integer programming approach produced good results which can easily be converted into a "schedule format" for use by CCTT system managers. Furthermore, the algorithm and CCTT schedule were developed using *Microsoft Excel®* which is an inexpensive "off-the-shelf" software that may be already available on most Army installations.

Another contribution is that, using this TSSP heuristic, subsets of training scenarios can be scheduled to try to identify the most efficient use of the CCTT system and allow training units to still meet their training objectives. For example, if three scenarios will satisfy a given set of training objectives, the heuristic can be used to select the scenario that best contributes to overall system utilization. This is acomplished by adding a constaint like Equation 8 where the sum of the three "training objective equivalent" scenarios must be less than or equal to one. When one of the three scenarios is selected for scheduling ($x_{ij} = 1$), the other two cannot be selected because their x_{ij} values must be zero. It also provides the unit with an idea of what resources might be available to conduct the scenario of their choice (available scheduling options).

The approach developed in this thesis also allows for an easy way of accounting for numerous precedence relationships (refer to matrix discussion in Chapter 4). By

establishing the order of scenario execution, the system may be set up ensure the "crawl-walk-run" method of training is used. This is usually the training scheme used by the Army.

Using cell references also provides a way to quickly update resource availability, scenario characteristics, or changing formulations. Essentially, it can be upgraded inexpensively.

Minimizing slack variables serves as a constant reminder of what resources are extensively used (binding) and what resources are almost always available. By analyzing the "binding" constraints, system bottlenecks, and slack variables efforts can be made to tailor CCTT site configuration so that Army dollars are effectively spent on the appropriate resources. For example, implementation of this algorithm has shown that conducting five simultaneous scenarios is seldom feasible. The Army has used this information to identify potential cost cutting areas before completely fielding the CCTT system (Wilkinson, personal communication, January 21, 1997).

6.3 Limitations of the TSSP Algorithm

Although the TSSP algorithm performed quite well in producing a feasible and efficient CCTT schedule, there exist some limitations.

First, using the greedy heuristic approach is not guaranteed to produce a global optimal solution. This is demonstrated in the fully constrained and partially constrained model solutions. The solution for the fully constrained model is also feasible for the

partially constrained model. In fact, the solution for the fully constrained model is a *better* solution in terms of overall resource utilization.

Second, use of this algorithm requires the user to have a good working knowledge of the *Microsoft Excel®* Solver function as well as a good understanding of the CCTT training system (particularly the interactions of training scenarios). From Chapter 3, it is known that the user must verify the feasibility of entering a constraint that requires the simultaneous scheduling requirement for two or more scenarios. This check is easily automated.

Third, the TSSP scheduling algorithm has the capability to select one of multiple scenarios which may satisfy a particular set of training objectives but it was <u>not</u> demonstrated here. The assumption (see Problem Statement) was that given a set of preselected training scenarios, how can we best schedule all of them in order to maximize resource utilization.

Last, the only measure of peformance (MOP) used for this algorithm was resource utilization. Although this is surely of interest to the managers of the CCTT system, it may not be the only MOP they require in the future. Training effectiveness and cost considerations may become equally as important as resource utilization.

6.4 Recommendations for Futher Research

During the development of this scheduling heuristic, several areas of additional research were identified.

They include:

(a) Using this algorithm for scheduling scenarios over a multi-day planning horizon. In the example where the single day's schedule was decomposed into a two day schedule, it was demonstrated that the total schedule duration could be reduced and resource utilization increased. From Chapter 2, it is known that minimizing total scheduling duration (makespan) *automatically* increases resource utilization. Therefore, extending this work from minimizing the "idle" resources to minimizing makespan may produce a better problem solution.

(b) Finding a way to exactly measure the effectiveness of this algorithm (determine its scheduling quality). To do this, one would need to know the optimal solution to the problem. This could prove to be a major undertaking except for small problems. A potential approach is to use the Demeulemeester and Herroelen (1992) algorithm on a problem when all scenarios must be scheduled.

(c) Improving the efficiency of this scheduling heuristic for scenarios. An improvement heuristic may produce resource utilizations that are close to optimal.

(d) Developing a way to relate CCTT schedules to overall training effectiveness. In this research, maximizing resource utilization was the selected scheduling criterion. However, a combination of maximizing resource utilization and

maximizing unit training opportunities would probably result in the best overall measure of training effectiveness.

(e) Developing "what if" programs that allows system managers to determine the impact of varying resources (and operator limitations). For example, what if SAF operators can effectively "manipulate" only forty entities instead of sixty? What is the overall impact to the CCTT system capabilities? What would be the impact of one additional (or one less) resource type? What happens to schedule durations as resources are manipulated?

(f) Developing software that performs the entire scheduling process once all of the resource and precedence constraints are entered. The stage by stage process is automatically conducted with slack variables recorded and a final CCTT schedule produced. This could be extended to track resource utilization of each resource type.

Appendix A

Excel Solver Output 1: Basic Model Results

Table 8

Stage 1 (Initial) for Basic Model (Resource Capacities Only)

									Current Time:		0	Next:	2.41	
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	0	4	0	1	1	3	1	0	0	2.12	*N/A*	*N/A*	*N/A*
X2	1	0	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	3.27
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	0	4	3	1	0	2	1	1	1	2.49	*N/A*	*N/A*	*N/A*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*N/A*	*N/A*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	0	0	4	0	0	1	1	0	0	2.1	*N/A*	*N/A*	*N/A*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	1	0	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	3.42
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	1	0	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	2.41
X16	0	0	4	2	1	3	3	1	0	0	2.48	*N/A*	*N/A*	*N/A*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	0	0	4	0	1	0	2	1	0	0	2.11	*N/A*	*N/A*	*N/A*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	0	0	0	4	0	0	1	1	0	0	2.31	*N/A*	*N/A*	*N/A*
X23	1	0	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	2.51
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		14	14	4	5	10	5	3	3				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	0	1	0	0	0	2	2				
Totals:			14	14	5	5	10	5	5	5		5 <=OBJ. FCTN		

Precedence Relationships:
None

Table 9

Stage 2 for Basic Model (Resource Capacities Only)

											Current Time:	2.41	Next:	2.51
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	1	0	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*2.12*
X2	1	0	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*0.86*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	0	4	3	1	0	2	1	1	1	2.49	*N/A*	*N/A*	*N/A*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*N/A*	*N/A*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	0	0	4	0	0	1	1	0	0	2.1	*N/A*	*N/A*	*N/A*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	1	0	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*1.01*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	0	4	2	1	3	3	1	0	0	2.48	*N/A*	*N/A*	*N/A*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	0	0	4	0	1	0	2	1	0	0	2.11	*N/A*	*N/A*	*N/A*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	0	0	0	4	0	0	1	1	0	0	2.31	*N/A*	*N/A*	*N/A*
X23	1	0	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*0.1*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		14	13	4	5	10	5	3	3				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	1	1	0	0	0	2	2				
Totals:			14	14	5	5	10	5	5	5		6 <=OBJ. FCTN		

Precedence Relationships:
None

Table 10

Stage 3 for Basic Model (Resource Capacities Only)

								Current Time:			2.51	Next:	3.27		
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	1	0	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*2.02*
X2	1	0	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*0.76*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	0	4	3	1	0	2	1	1	1	2.49	*N/A*	*N/A*	*N/A*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*N/A*	*N/A*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	1	0	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*2.1*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	1	0	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*0.91*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	0	4	2	1	3	3	1	0	0	2.48	*N/A*	*N/A*	*N/A*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	0	0	4	0	1	0	2	1	0	0	2.11	*N/A*	*N/A*	*N/A*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	0	0	0	4	0	0	1	1	0	0	2.31	*N/A*	*N/A*	*N/A*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		12	13	4	5	10	5	2	2				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			2	1	1	0	0	0	3	3				
Totals:			14	14	5	5	10	5	5	5		10 <=OBJ. FCTN		

Precedence Relationships:
None

Table 11

Stage 4 for Basic Model (Resource Capacities Only)

Current Time: 3.27 Next: 3.42

			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	1	0	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*1.26*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	0	4	3	1	0	2	1	1	1	2.49	*N/A*	*N/A*	*N/A*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*N/A*	*N/A*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	1	0	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*1.34*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	1	0	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*0.15*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	1	0	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*2.48*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	0	0	4	0	1	0	2	1	0	0	2.11	*N/A*	*N/A*	*N/A*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	0	0	0	4	0	0	1	1	0	0	2.31	*N/A*	*N/A*	*N/A*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		12	13	4	5	10	4	2	2				
Available:	5		*14*	*14*	5	5	*10*	5	5	5				
Slack:			2	1	1	0	0	1	3	3				
Totals:			14	14	5	5	10	5	5	5		11 <=OBJ. FCTN		

Precedence Relationships:
None

Table 12

Stage 5 for Basic Model (Resource Capacities Only)

								Current Time:			3.42	Next:	4.53	
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	1	0	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*1.11*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	1	0	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*2.49*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*N/A*	*N/A*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	1	0	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*1.19*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	1	0	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*2.33*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	0	0	4	0	1	0	2	1	0	0	2.11	*N/A*	*N/A*	*N/A*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	1	0	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*2.31*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	5		12	13	3	4	10	5	1	1				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			2	1	2	1	0	0	4	4				
Totals:			14	14	5	5	10	5	5	5		14 <=OBJ. FCTN		

Precedence Relationships:
None

Table 13

Stage 6 for Basic Model (Resource Capacities Only)

										Current Time:	4.53	Next:	4.61	
	*****Resource Requirements*****										Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	1	0	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*1.38*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*N/A*	*N/A*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	1	0	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*0.08*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	1	0	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*1.22*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	1	0	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*2.11*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	1	0	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*1.2*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		12	13	3	3	9	5	1	1				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			2	1	2	2	1	0	4	4				
Totals:			14	14	5	5	10	5	5	5		16 <=OBJ. FCTN		

Precedence Relationships:
None

Table 14

Stage 7 for Basic Model (Resource Capacities Only)

								Current Time:			4.61	Next:	5.73		
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	1	0	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*1.3*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*N/A*	*N/A*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	1	0	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*1.14*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	1	0	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*2.03*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	1	0	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*1.12*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		12	9	3	3	8	4	1	1				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			2	5	2	2	2	1	4	4				
Totals:			14	14	5	5	10	5	5	5		22 <=OBJ. FCTN		

Precedence Relationships:
None

Table 15

Stage 8 for Basic Model (Resource Capacities Only)

Current Time: 5.73 Next: 5.75

			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	1	0	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*0.18*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	0	0	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*2.47*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	1	0	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*0.02*
X17	0	0	4	3	0	0	2	2	1	1	3.3	*N/A*	*N/A*	*N/A*
X18	1	0	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*0.91*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		14	9	4	4	10	4	1	1				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	5	1	1	0	1	4	4				
Totals:			14	14	5	5	10	5	5	5		16 <=OBJ. FCTN		

Precedence Relationships:
None

Table 16

Stage 9 for Basic Model (Resource Capacities Only)

									Current Time:		5.75	Next:	5.91	
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	1	0	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*0.16*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	1	0	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*2.45*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	1	0	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*3.3*
X18	1	0	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*0.89*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	0	2	4	1	1	3	1	0	0	2.24	*N/A*	*N/A*	*N/A*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		14	10	3	1	9	5	2	2				
Available:	5		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	4	2	4	1	0	3	3				
Totals:			14	14	5	5	10	5	5	5		17 <=OBJ. FCTN		

Precedence Relationships:
None

Table 17

Stage 10 for Basic Model (Resource Capacities Only)

											Current Time: 5.91	Next: 6.64		
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	0	4	2	0	1	1	1	1	0	2.39	*N/A*	*N/A*	*N/A*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	1	0	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*2.29*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	1	0	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*3.14*
X18	1	0	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*0.73*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	1	0	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*2.24*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		12	11	3	2	10	5	1	1				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			2	3	2	3	0	0	4	4				
Totals:			14	14	5	5	10	5	5	5	18 <=OBJ. FCTN			

Precedence Relationships:
None

Table 18

Stage 11 for Basic Model (Resource Capacities Only)

											Current Time:	6.64	Next:	8.15
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	1	0	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*2.39*
X6	0	0	1	4	1	1	3	1	0	0	2.45	*N/A*	*N/A*	*N/A*
X7	1	0	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*1.56*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*	*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	1	0	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*2.41*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	1	0	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*1.51*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		12	13	2	3	9	5	2	1				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			2	1	3	2	1	0	3	4				
Totals:			14	14	5	5	10	5	5	5		16 <=OBJ. FCTN		

Precedence Relationships:
None

Table 19

Stage 12 for Basic Model (Resource Capacities Only)

											Current Time:	8.15	Next:	8.2	
			*****Resource Requirements*****									Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start		End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*		*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*		*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*		*N/A*	*N/A*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*		*5.91*	*End*
X5	1	0	4	2	0	1	1	1	1	0	2.39	*6.64*		*9.03*	*0.88*
X6	1	0	1	4	1	1	3	1	0	0	2.45	*8.15*		*10.6*	*2.45*
X7	1	0	2	4	1	1	3	1	0	0	2.47	*5.73*		*8.2*	*0.05*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*		*N/A*	*N/A*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*		*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*		*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*		*N/A*	*N/A*
X12	0	0	5	5	1	1	2	1	2	1	3.22	*N/A*		*N/A*	*N/A*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*		*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*		*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*		*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*		*5.75*	*End*
X17	1	0	4	3	0	0	2	2	1	1	3.3	*5.75*		*9.05*	*0.9*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*		*6.64*	*End*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*		*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*		*N/A*	*N/A*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*		*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*		*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*		*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*		*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*		*N/A*	*N/A*
Res. Used:	4		11	13	2	3	9	5	2	1					
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*					
Slack:			3	1	3	2	1	0	3	4					
Totals:			14	14	5	5	10	5	5	5		17 <=OBJ. FCTN			

Precedence Relationships:
None

Table 20

Stage 13 for Basic Model (Resource Capacities Only)

												Current Time:	8.2	Next:	9.03
			*****Resource Requirements*****									Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	1	0	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*2.4*
X7	1	0	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*N/A*
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	1	0	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*3.2*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	1	0	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*0.85*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	0	4	1	0	1	1	1	0	0	2.36	*N/A*	*N/A*	*N/A*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		14	14	2	3	8	5	4	2				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	0	3	2	2	0	1	3				
Totals:			14	14	5	5	10	5	5	5	11 <=OBJ. FCTN			

Precedence Relationships:

None

Table 21

Stage 14 for Basic Model (Resource Capacities Only)

											Current Time:	9.03	Next:	9.05	
			*****Resource Requirements*****									Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain	
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*	
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*	
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*	
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*	
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*	
X6	1	0	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*1.57*	
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*	
X8	0	0	3	4	0	0	1	1	1	1	3.12	*N/A*	*N/A*	*N/A*	
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*	
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*	
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*	
X12	1	0	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*2.37*	
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*	
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*	
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*	
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*	
X17	1	0	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*0.02*	
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*	
X19	1	0	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*2.37*	
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*	
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*	
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*	
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*	
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*	
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*	
Res. Used:	4		14	13	2	3	8	5	3	2					
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*					
Slack:			0	1	3	2	2	0	2	3					
Totals:			14	14	5	5	10	5	5	5		13 <=OBJ. FCTN			

Precedence Relationships:
None

Table 22

Stage 15 for Basic Model (Resource Capacities Only)

											Current Time:	9.05	Next:	10.6
	*****Resource Requirements*****										Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	1	0	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*1.55*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	1	0	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*3.15*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	1	0	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*2.35*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	1	0	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*2.35*
X20	0	0	1	4	1	1	3	1	0	0	2.28	*N/A*	*N/A*	*N/A*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		13	14	2	3	7	4	3	2				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			1	0	3	2	3	1	2	3				
Totals:			14	14	5	5	10	5	5	5	15 <=OBJ. FCTN			

Precedence Relationships:
None

Table 23

Stage 16 for Basic Model (Resource Capacities Only)

												Current Time:	10.6	Next:	11.4
			*****Resource Requirements*****									Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	1	0	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*1.6*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	0	7	4	2	2	3	3	2	2	3.38	*N/A*	*N/A*	*N/A*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	1	0	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*0.8*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	1	0	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*0.8*
X20	1	0	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*2.28*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	4		13	14	2	3	7	4	3	2				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			1	0	3	2	3	1	2	3				
Totals:			14	14	5	5	10	5	5	5		15 <=OBJ. FCTN		

Precedence Relationships:
None

Table 24

Stage 17 for Basic Model (Resource Capacities Only)

											Current Time:	11.4	Next:	12.2
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	0	4	0	0	0	2	1	0	0	2.19	*N/A*	*N/A*	*N/A*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	1	0	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*0.8*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	1	0	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*	*3.38*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*End*
X20	1	0	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*1.5*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	3		11	12	3	3	7	5	3	3				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			3	2	2	2	3	0	2	2				
Totals:			14	14	5	5	10	5	5	5		16 <=OBJ. FCTN		

Precedence Relationships:
None

Table 25

Stage 18 for Basic Model (Resource Capacities Only)

											Current Time:	12.2	Next:	12.9	
			*****Resource Requirements*****									Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	1	0	4	0	0	0	2	1	0	0	2.19	*12.2*	*14.4*	*2.19*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*End*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	1	0	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*	*2.6*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*End*
X20	1	0	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*0.7*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	3		12	8	3	3	8	5	2	2				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			2	6	2	2	2	0	3	3				
Totals:			14	14	5	5	10	5	5	5		20 <=OBJ. FCTN		

Precedence Relationships:

None

Table 26

Stage 19 for Basic Model (Resource Capacities Only)

Current Time: 12.9 Next: 14.4

			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	1	0	4	0	0	0	2	1	0	0	2.19	*12.2*	*14.4*	*1.5*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*End*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	1	0	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*	*1.9*
X11	0	0	7	4	2	2	3	2	2	2	3.47	*N/A*	*N/A*	*N/A*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2	3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*End*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*End*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	2		11	4	2	2	5	4	2	2				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			3	10	3	3	5	1	3	3				
Totals:			14	14	5	5	10	5	5	5	31 <=OBJ. FCTN			

Precedence Relationships:
None

Table 27

Stage 20 for Basic Model (Resource Capacities Only)

												Current Time: 14.4	Next: 14.8		
			*****Resource Requirements*****									Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV		Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0		2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0		3.27	*0*	*3.27*	*End*
X3	0	1	4	0	0	0	2	1	0	0		2.19	*12.2*	*14.4*	*End*
X4	0	1	4	3	1	0	2	1	1	1		2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0		2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0		2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0		2.47	*5.73*	*8.2*	*End*
X8	0	1	3	4	0	0	1	1	1	1		3.12	*9.05*	*12.2*	*End*
X9	0	1	0	4	0	0	1	1	0	0		2.1	*2.51*	*4.61*	*End*
X10	1	0	7	4	2	2	3	3	2	2		3.38	*11.4*	*14.8*	*0.4*
X11	1	0	7	4	2	2	3	2	2	2		3.47	*14.4*	*17.9*	*3.5*
X12	0	1	5	5	1	1	2	1	2	1		3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2		3.42	*0*	*3.42*	*End*
X14	0	0	7	7	2	2	3	3	3	2		3.59	*N/A*	*N/A*	*N/A*
X15	0	1	4	1	1	1	3	1	0	0		2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0		2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1		3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0		2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0		2.36	*9.03*	*11.4*	*End*
X20	0	1	1	4	1	1	3	1	0	0		2.28	*10.6*	*12.9*	*End*
X21	0	1	2	4	1	1	3	1	0	0		2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0		2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1		2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2		3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2		3.55	*N/A*	*N/A*	*N/A*
Res. Used:	2		14	8	4	4	6	5	4	4					
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*					
Slack:			0	6	1	1	4	0	1	1					
Totals:			14	14	5	5	10	5	5	5		14 <=OBJ. FCTN			

Precedence Relationships:

None

Table 28

Stage 21 for Basic Model (Resource Capacities Only)

										Current Time:	14.8	Next:	17.9	
	*****Resource Requirements*****										Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	1	4	0	0	0	2	1	0	0	2.19	*12.2*	*14.4*	*End*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*End*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	1	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*	*End*
X11	1	0	7	4	2	2	3	2	2	2	3.47	*14.4*	*17.9*	*3.1*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	1	0	7	7	2	2	3	3	3	2	3.59	*14.8*	*18.4*	*3.6*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*End*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*End*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	0	7	4	2	2	3	2	2	2	3.45	*N/A*	*N/A*	*N/A*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	2		14	11	4	4	6	5	5	4				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	3	1	1	4	0	0	1				
Totals:			14	14	5	5	10	5	5	5		10 <=OBJ. FCTN		

Precedence Relationships:

None

Table 29

Stage 22 for Basic Model (Resource Capacities Only)

								Current Time:			17.9	Next:	18.4		
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	1	4	0	0	0	2	1	0	0	2.19	*12.2*	*14.4*	*End*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*End*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	1	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*	*End*
X11	0	1	7	4	2	2	3	2	2	2	3.47	*14.4*	*17.9*	*End*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	1	0	7	7	2	2	3	3	3	2	3.59	*14.8*	*18.4*	*0.5*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*End*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*End*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	1	0	7	4	2	2	3	2	2	2	3.45	*17.9*	*21.4*	*3.45*
X25	0	0	7	4	2	2	3	2	2	2	3.55	*N/A*	*N/A*	*N/A*
Res. Used:	2		14	11	4	4	6	5	5	4				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	3	1	1	4	0	0	1				
Totals:			14	14	5	5	10	5	5	5		10 <=OBJ. FCTN		

Precedence Relationships:
None

Table 30

Stage 23 for Basic Model (Resource Capacities Only)

															Current Time: 18.4 Next: 21.4
			*****Resource Requirements*****								Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	1	4	0	0	0	2	1	0	0	2.19	*12.2*	*14.4*	*End*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*End*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	1	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*	*End*
X11	0	1	7	4	2	2	3	2	2	2	3.47	*14.4*	*17.9*	*End*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	1	7	7	2	2	3	3	3	2	3.59	*14.8*	*18.4*	*End*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*End*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*End*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	1	0	7	4	2	2	3	2	2	2	3.45	*17.9*	*21.4*	*3*
X25	1	0	7	4	2	2	3	2	2	2	3.55	*18.4*	*22*	*3.55*
Res. Used:	2		14	8	4	4	6	4	4	4				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			0	6	1	1	4	1	1	1				
Totals:			14	14	5	5	10	5	5	5	15 <=OBJ. FCTN			

Precedence Relationships:
None

Table 31

Stage 24 for Basic Model (Resource Capacities Only)

												Current Time:	21.4	Next:	22
			*****Resource Requirements*****									Scen.			Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End	Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*	*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*	*End*
X3	0	1	4	0	0	0	2	1	0	0	2.19	*12.2*	*14.4*	*End*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*	*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*	*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*	*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*	*End*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*	*End*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*	*End*
X10	0	1	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*	*End*
X11	0	1	7	4	2	2	3	2	2	2	3.47	*14.4*	*17.9*	*End*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*	*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*	*End*
X14	0	1	7	7	2	2	3	3	3	2	3.59	*14.8*	*18.4*	*End*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*	*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*	*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*	*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*	*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*	*End*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*	*End*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*	*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*	*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*	*End*
X24	0	1	7	4	2	2	3	2	2	2	3.45	*17.9*	*21.4*	*End*
X25	1	0	7	4	2	2	3	2	2	2	3.55	*18.4*	*22*	*0.6*
Res. Used:	1		7	4	2	2	3	2	2	2				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			7	10	3	3	7	3	3	3				
Totals:			14	14	5	5	10	5	5	5		39 <=OBJ. FCTN		

Precedence Relationships:
None

Table 32

Stage 25 (Final) for Basic Model (Resource Capacities Only)

											Current Time:	21.4	Next:	22	
			*****Resource Requirements*****								Scen.				Time
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End		Remain
X1	0	1	4	0	1	1	3	1	0	0	2.12	*2.41*	*4.53*		*End*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*0*	*3.27*		*End*
X3	0	1	4	0	0	0	2	1	0	0	2.19	*12.2*	*14.4*		*End*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*3.42*	*5.91*		*End*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*6.64*	*9.03*		*End*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*8.15*	*10.6*		*End*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*5.73*	*8.2*		*End*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*9.05*	*12.2*		*End*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*2.51*	*4.61*		*End*
X10	0	1	7	4	2	2	3	3	2	2	3.38	*11.4*	*14.8*		*End*
X11	0	1	7	4	2	2	3	2	2	2	3.47	*14.4*	*17.9*		*End*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.2*	*11.4*		*End*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*0*	*3.42*		*End*
X14	0	1	7	7	2	2	3	3	3	2	3.59	*14.8*	*18.4*		*End*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*0*	*2.41*		*End*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*3.27*	*5.75*		*End*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*5.75*	*9.05*		*End*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*4.53*	*6.64*		*End*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*9.03*	*11.4*		*End*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*10.6*	*12.9*		*End*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.91*	*8.15*		*End*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*3.42*	*5.73*		*End*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*		*End*
X24	0	1	7	4	2	2	3	2	2	2	3.45	*17.9*	*21.4*		*End*
X25	0	1	7	4	2	2	3	2	2	2	3.55	*18.4*	22		*End*
Res. Used:	0		0	0	0	0	0	0	0	0					
Available:	5		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*					
Slack:			14	14	5	5	10	5	5	5					
Totals:			14	14	5	5	10	5	5	5		63 <=OBJ. FCTN			

Precedence Relationships:

None

Appendix B

Excel Solver Output 2: Partially Constrained Model Results

Table 33

Final Schedule for Partially Constrained Model (Individual Precedence Constraints and Requirement for Three Simultaneous Scenarios)

											Current Time:	23.81	Next:	0
			*****Resource Requirements*****									Scen.		
Scen #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV		Duration	Start	End
X1	0	1	4	0	1	1	3	1	0	0		2.12	*6.92*	*9.04*
X2	0	1	4	2	1	3	3	2	0	0		3.27	*18.05*	*21.32*
X3	0	1	4	0	0	0	2	1	0	0		2.19	*9.04*	*11.23*
X4	0	1	4	3	1	0	2	1	1	1		2.49	*21.32*	*23.81*
X5	0	1	4	2	0	1	1	1	1	0		2.39	*0*	*2.39*
X6	0	1	1	4	1	1	3	1	0	0		2.45	*0*	*2.45*
X7	0	1	2	4	1	1	3	1	0	0		2.47	*0*	*2.47*
X8	0	1	3	4	0	0	1	1	1	1		3.12	*2.47*	*5.59*
X9	0	1	0	4	0	0	1	1	0	0		2.1	*2.45*	*4.55*
X10	0	1	7	4	2	2	3	3	2	2		3.38	*14.23*	*17.61*
X11	0	1	7	4	2	2	3	2	2	2		3.47	*3.45*	*6.92*
X12	0	1	5	5	1	1	2	1	2	1		3.22	*14.83*	*18.05*
X13	0	1	4	7	2	1	3	1	2	2		3.42	*6.92*	*10.34*
X14	0	1	7	7	2	2	3	3	3	2		3.59	*10.64*	*14.23*
X15	0	1	4	1	1	1	3	1	0	0		2.41	*2.45*	*4.86*
X16	0	1	4	2	1	3	3	1	0	0		2.48	*4.86*	*7.34*
X17	0	1	4	3	0	0	2	2	1	1		3.3	*7.34*	*10.64*
X18	0	1	4	0	1	0	2	1	0	0		2.11	*17.61*	*19.72*
X19	0	1	4	1	0	1	1	1	0	0		2.36	*17.61*	*19.97*
X20	0	1	1	4	1	1	3	1	0	0		2.28	*17.61*	*19.89*
X21	0	1	2	4	1	1	3	1	0	0		2.24	*9.04*	*11.28*
X22	0	1	0	4	0	0	1	1	0	0		2.31	*4.55*	*6.86*
X23	0	1	2	4	0	0	1	1	1	1		2.51	*5.59*	*8.1*
X24	0	1	7	4	2	2	3	2	2	2		3.45	*0*	*3.45*
X25	0	1	7	4	2	2	3	2	2	2		3.55	*11.28*	*14.83*
Res. Used:	0		0	0	0	0	0	0	0	0				
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*				
Slack:			14	14	5	5	10	5	5	5		63 <=OBJ. FCTN		
Totals:			14	14	5	5	10	5	5	5				

Precedence Relationships:

1) X1 before X2	0	*4) X15 before X16*	0
2) X2 before X4	0	*5) X17 before X12*	0
3) X9 before X21	0	*6) X18 = X19 = X20*	

Appendix C

Excel Solver Output 3: Fully Constrained Model Results

Table 34

Final Schedule for Fully Constrained Model (Individual and Group Preceden Constraints and Requirement for Three Simultaneous Scenarios)

											Current Time:	23.32	Next:	0
			*****Resource Requirements*****								Scen.		
Scen #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End
X1	0	1	4	0	1	1	3	1	0	0	2.12	*0*	*2.12*
X2	0	1	4	2	1	3	3	2	0	0	3.27	*4.76*	*8.03*
X3	0	1	4	0	0	0	2	1	0	0	2.19	*2.12*	*4.31*
X4	0	1	4	3	1	0	2	1	1	1	2.49	*8.03*	*10.52*
X5	0	1	4	2	0	1	1	1	1	0	2.39	*0*	*2.39*
X6	0	1	1	4	1	1	3	1	0	0	2.45	*0*	*2.45*
X7	0	1	2	4	1	1	3	1	0	0	2.47	*2.51*	*4.98*
X8	0	1	3	4	0	0	1	1	1	1	3.12	*0*	*3.12*
X9	0	1	0	4	0	0	1	1	0	0	2.1	*3.12*	*5.22*
X10	0	1	7	4	2	2	3	3	2	2	3.38	*16.47*	*19.85*
X11	0	1	7	4	2	2	3	2	2	2	3.47	*19.85*	*23.32*
X12	0	1	5	5	1	1	2	1	2	1	3.22	*8.28*	*11.5*
X13	0	1	4	7	2	1	3	1	2	2	3.42	*19.88*	*23.3*
X14	0	1	7	7	2	2	3	3	3	2	3.59	*12.88*	*16.47*
X15	0	1	4	1	1	1	3	1	0	0	2.41	*2.39*	*4.8*
X16	0	1	4	2	1	3	3	1	0	0	2.48	*8.03*	*10.51*
X17	0	1	4	3	0	0	2	2	1	1	3.3	*4.98*	*8.28*
X18	0	1	4	0	1	0	2	1	0	0	2.11	*10.52*	*12.63*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*10.52*	*12.88*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*10.52*	*12.8*
X21	0	1	2	4	1	1	3	1	0	0	2.24	*5.22*	*7.46*
X22	0	1	0	4	0	0	1	1	0	0	2.31	*2.45*	*4.76*
X23	0	1	2	4	0	0	1	1	1	1	2.51	*0*	*2.51*
X24	0	1	7	4	2	2	3	2	2	2	3.45	*16.43*	*19.88*
X25	0	1	7	4	2	2	3	2	2	2	3.55	*12.88*	*16.43*
Res. Used:	0		0	0	0	0	0	0	0	0			
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*			
Slack:			14	14	5	5	10	5	5	5		63	<=OBJ. FCTN
Totals:			14	14	5	5	10	5	5	5			

Precedence Relationships:

1) X1 before X2	0	*5) X17 before X12*	0
2) X2 before X4	0	*6) X18 = X19 = X20*	
3) X9 before X21	0	*7) all platoons before companies*	1
4) X15 before X16	0		

Appendix D

Excel Solver Output 4: Final Results Using McGinnis and Phelan's (1996) Scenarios

(SAF Workstation Constraint Only)

Table 35

Final Results Generated By TSSP Scheduling Heuristic Using McGinnis and Phelan Scenarios (SAF Workstation Only Constraint)

													Current Time:	13	Next: 0
			*****Resource Requirements*****										Scen.		
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV			Duration	Start	End
X1	0	1	0	4	2	0	2	1	0	0			2	*0*	*2*
X2	0	1	0	4	2	0	2	1	0	0			2	*0*	*2*
X3	0	1	0	4	2	0	2	1	0	0			2	*0*	*2*
X4	0	1	4	0	0	0	2	1	0	0			2	*0*	*2*
X5	0	1	2	4	0	0	2	1	0	0			2	*0*	*2*
X6	0	1	2	4	0	0	2	1	0	0			2	*2*	*4*
X7	0	1	0	4	2	0	2	1	0	0			2	*2*	*4*
X8	0	1	0	4	2	0	1	1	0	0			2	*4*	*6*
X9	0	1	4	0	0	0	1	1	0	0			2	*5*	*7*
X10	0	1	4	0	0	0	1	1	0	0			2	*5*	*7*
X11	0	1	0	4	2	0	1	2	1	1			2	*5*	*7*
X12	0	1	4	10	4	1	2	2	1	1			3	*2*	*5*
X13	0	1	4	10	4	1	2	2	1	1			3	*4*	*7*
X14	0	1	10	4	2	1	2	2	1	1			3	*2*	*5*
X15	0	1	10	4	2	1	2	2	1	1			3	*2*	*5*
X16	1	0	14	14	3	2	10	5	2	4			6	*7*	*13*
Res. Used:	1		14	14	3	2	10	5	2	4					
Available:	*5*		*14*	*14*	*3*	*2*	*10*	*5*	*2*	*4*					
Slack:			2	2	1	2	0	0	2	4				0 <=OBJ. FCTN	
Totals:			16	16	4	4	10	5	4	8					

Precedence Relationships:
1) all others scheduled before battalion 1

Appendix E

Excel Solver Output 5: Final Results Using McGinnis and Phelan's (1996) Scenarios

(All Resource Constraints)

Table 36

Final Results Generated By TSSP Scheduling Heuristic Using McGinnis and Phelan Scenarios (All Resource Constraints)

							Current Time:			18	Next:	0
			*****Resource Requirements*****							Scen.		
Scen. #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End
X1	0	1	0	4	2	0	2	1	0	0	2	*0*	*2*
X2	0	1	0	4	2	0	2	1	0	0	2	*10*	*12*
X3	0	1	0	4	2	0	2	1	0	0	2	*8*	*10*
X4	0	1	4	0	0	0	2	1	0	0	2	*0*	*2*
X5	0	1	2	4	0	0	2	1	0	0	2	*8*	*10*
X6	0	1	2	4	0	0	2	1	0	0	2	*8*	*10*
X7	0	1	0	4	2	0	2	1	0	0	2	*6*	*8*
X8	0	1	0	4	2	0	1	1	0	0	2	*10*	*12*
X9	0	1	4	0	0	0	1	1	0	0	2	*6*	*8*
X10	0	1	4	0	0	0	1	1	0	0	2	*6*	*8*
X11	0	1	0	4	2	0	1	1	1	1	2	*0*	*2*
X12	0	1	4	10	4	1	2	2	1	1	3	*5*	*8*
X13	0	1	4	10	4	1	2	2	1	1	3	*2*	*5*
X14	0	1	10	4	2	1	2	2	1	1	3	*0*	*3*
X15	0	1	10	4	2	1	2	2	1	1	3	*3*	*6*
X16	0	1	14	14	3	2	10	5	2	4	6	*12*	*18*
Res. Used:	0		0	0	0	0	0	0	0	0			
Available:	*5*		*14*	*14*	*6*	*5*	*10*	*5*	*5*	*5*			
Slack:			*14*	*14*	*6*	*5*	*10*	*5*	*5*	*5*		64 <=OBJ. FCTN	
Totals:			14	14	6	5	10	5	5	5			

Precedence Relationships:

1) all others scheduled before battalion 1

Appendix F

Two Day Scheduling Results for Partially Constrained Model

Table 37

Final Schedule for Partially Constrained Model (Day 1)

												Current Time:	14.83	Next:	0
			*****Resource Requirements*****									Scen.			
Scen #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV		Duration		Start	End
X1	0	1	4	0	1	1	3	1	0	0		2.12		*6.92*	*9.04*
X2	0	1	4	2	1	3	3	2	0	0		3.27		Day #2	
X3	0	1	4	0	0	0	2	1	0	0		2.19		*9.04*	*11.23*
X4	0	1	4	3	1	0	2	1	1	1		2.49		Day #2	
X5	0	1	4	2	0	1	1	1	1	0		2.39		*0*	*2.39*
X6	0	1	1	4	1	1	3	1	0	0		2.45		*0*	*2.45*
X7	0	1	2	4	1	1	3	1	0	0		2.47		*0*	*2.47*
X8	0	1	3	4	0	0	1	1	1	1		3.12		*2.47*	*5.59*
X9	0	1	0	4	0	0	1	1	0	0		2.1		*2.45*	*4.55*
X10	0	1	7	4	2	2	3	3	2	2		3.38		Day #2	
X11	0	1	7	4	2	2	3	2	2	2		3.47		*3.45*	*6.92*
X12	0	1	5	5	1	1	2	1	2	1		3.22		Day #2	
X13	0	1	4	7	2	1	3	1	2	2		3.42		*6.92*	*10.34*
X14	0	1	7	7	2	2	3	3	3	2		3.59		*10.64*	*14.23*
X15	0	1	4	1	1	1	3	1	0	0		2.41		*2.45*	*4.86*
X16	0	1	4	2	1	3	3	1	0	0		2.48		*4.86*	*7.34*
X17	0	1	4	3	0	0	2	2	1	1		3.3		*7.34*	*10.64*
X18	0	1	4	0	1	0	2	1	0	0		2.11		Day #2	
X19	0	1	4	1	0	1	1	1	0	0		2.36		Day #2	
X20	0	1	1	4	1	1	3	1	0	0		2.28		Day #2	
X21	0	1	2	4	1	1	3	1	0	0		2.24		*9.04*	*11.28*
X22	0	1	0	4	0	0	1	1	0	0		2.31		*4.55*	*6.86*
X23	0	1	2	4	0	0	1	1	1	1		2.51		*5.59*	*8.1*
X24	0	1	7	4	2	2	3	2	2	2		3.45		*0*	*3.45*
X25	0	1	7	4	2	2	3	2	2	2		3.55		*11.28*	*14.83*
Res. Used:	0		0	0	0	0	0	0	0	0					
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*					
Slack:			14	14	5	5	10	5	5	5				63 <=OBJ. FCTN	
Totals:			14	14	5	5	10	5	5	5					

Precedence Relationships:

1) X1 before X2	0	*4) X15 before X16*	0
2) X2 before X4	0	*5) X17 before X12*	0
3) X9 before X21	0	*6) X18 = X19 = X20*	

Table 38

Final Schedule for Partially Constrained Model (Day 2)

													Current Time:	8.04	Next:	0
			*****Resource Requirements*****										Scen.			
Scen #	Xij	Yij	M1	M2	DI	HV	SAF	AR	PC	FV	Duration	Start	End
X1	0	1	4	0	1	1	3	1	0	0	2.12	Day #1	
X2	0	1	4	2	1	3	3	2	0	0	3.27	*2.28*	*5.55*
X3	0	1	4	0	0	0	2	1	0	0	2.19	Day #1	
X4	0	1	4	3	1	0	2	1	1	1	2.49	*5.55*	*8.04*
X5	0	1	4	2	0	1	1	1	1	0	2.39	Day #1	
X6	0	1	1	4	1	1	3	1	0	0	2.45	Day #1	
X7	0	1	2	4	1	1	3	1	0	0	2.47	Day #1	
X8	0	1	3	4	0	0	1	1	1	1	3.12	Day #1	
X9	0	1	0	4	0	0	1	1	0	0	2.1	Day #1	
X10	0	1	7	4	2	2	3	3	2	2	3.38	*3.22*	*6.6*
X11	0	1	7	4	2	2	3	2	2	2	3.47	Day #1	
X12	0	1	5	5	1	1	2	1	2	1	3.22	*0*	*3.22*
X13	0	1	4	7	2	1	3	1	2	2	3.42	Day #1	
X14	0	1	7	7	2	2	3	3	3	2	3.59	Day #1	
X15	0	1	4	1	1	1	3	1	0	0	2.41	Day #1	
X16	0	1	4	2	1	3	3	1	0	0	2.48	Day #1	
X17	0	1	4	3	0	0	2	2	1	1	3.3	Day #1	
X18	0	1	4	0	1	0	2	1	0	0	2.11	*0*	*2.11*
X19	0	1	4	1	0	1	1	1	0	0	2.36	*0*	*2.36*
X20	0	1	1	4	1	1	3	1	0	0	2.28	*0*	*2.28*
X21	0	1	2	4	1	1	3	1	0	0	2.24	Day #1	
X22	0	1	0	4	0	0	1	1	0	0	2.31	Day #1	
X23	0	1	2	4	0	0	1	1	1	1	2.51	Day #1	
X24	0	1	7	4	2	2	3	2	2	2	3.45	Day #1	
X25	0	1	7	4	2	2	3	2	2	2	3.55	Day #1	
Res. Used:	0		0	0	0	0	0	0	0	0			
Available:	*5*		*14*	*14*	*5*	*5*	*10*	*5*	*5*	*5*			
Slack:			14	14	5	5	10	5	5	5		63 <=OBJ. FCTN	
Totals:			14	14	5	5	10	5	5	5			

Precedence Relationships:

1) X1 before X2	0	*4) X15 before X16*	0
2) X2 before X4	0	*5) X17 before X12*	0
3) X9 before X21	0	*6) X18 = X19 = X20*	

Appendix G

Table Showing the Cell Functions in the Excel Spreadsheet for

the Fully Constrained Problem

Table 39

Functions Used in Excel

	A	B	C	D	E
1	Scen #			Resource Req'mts	
2		Xij	Yij	M1	M2
3	*X1*	0	0	4	0
4	*X2*	0	0	4	2
5	*X3*	0	0	4	0
6	*X4*	0	0	4	3
7	*X5*	0	0	4	2
8	*X6*	0	0	1	4
9	*X7*	0	0	2	4
10	*X8*	0	0	3	4
11	*X9*	0	0	0	4
12	*X10*	0	0	7	4
13	*X11*	0	0	7	4
14	*X12*	0	0	5	5
15	*X13*	0	0	4	7
16	*X14*	0	0	7	7
17	*X15*	0	0	4	1
18	*X16*	0	0	4	2
19	*X17*	0	0	4	3
20	*X18*	0	0	4	0
21	*X19*	0	0	4	1
22	*X20*	0	0	1	4
23	*X21*	0	0	2	4
24	*X22*	0	0	0	4
25	*X23*	0	0	2	4
26	*X24*	0	0	7	4
27	*X25*	0	0	7	4

	F	G	H
1			
2	DI	HV	WS
3	1	1	3
4	1	3	3
5	0	0	2
6	1	0	2
7	0	1	1
8	1	1	3
9	1	1	3
10	0	0	1
11	0	0	1
12	2	2	3
13	2	2	3
14	1	1	2
15	2	1	3
16	2	2	3
17	1	1	3
18	1	3	3
19	0	0	2
20	1	0	2
21	0	1	1
22	1	1	3
23	1	1	3
24	0	0	1
25	0	0	1
26	2	2	3
27	2	2	3
28			
29			
30			
31			
32			

	I	J	K	L
1				Current Time:
2	AR	PC	FV	Scenario Duration
3	1	0	0	2.12
4	2	0	0	3.27
5	1	0	0	2.19
6	1	1	1	2.49
7	1	1	0	2.39
8	1	0	0	2.45
9	1	0	0	2.47
10	1	1	1	3.12
11	1	0	0	2.1
12	3	2	2	3.38
13	2	2	2	3.47
14	1	2	1	3.22
15	1	2	2	3.42
16	3	3	2	3.59
17	1	0	0	2.41
18	1	0	0	2.48
19	2	1	1	3.3
20	1	0	0	2.11
21	1	0	0	2.36
22	1	0	0	2.28
23	1	0	0	2.24
24	1	0	0	2.31
25	1	1	1	2.51
26	2	2	2	3.45
27	2	2	2	3.55
28				
29				
30				
31				
32				

	M	N	O
1	0	Next:	=MIN(O3:O27)+M1
2	Start	End	Time Remaining
3	=IF(B3=1,$M$1,"N/A")	=IF(B3=1,$M$1+L3,"N/A")	=IF(N3="N/A","N/A",N3-$M$1)
4	=IF(B4=1,$M$1,"N/A")	=IF(B4=1,$M$1+L4,"N/A")	=IF(N4="N/A","N/A",N4-$M$1)
5	=IF(B5=1,$M$1,"N/A")	=IF(B5=1,$M$1+L5,"N/A")	=IF(N5="N/A","N/A",N5-$M$1)
6	=IF(B6=1,$M$1,"N/A")	=IF(B6=1,$M$1+L6,"N/A")	=IF(N6="N/A","N/A",N6-$M$1)
7	=IF(B7=1,$M$1,"N/A")	=IF(B7=1,$M$1+L7,"N/A")	=IF(N7="N/A","N/A",N7-$M$1)
8	=IF(B8=1,$M$1,"N/A")	=IF(B8=1,$M$1+L8,"N/A")	=IF(N8="N/A","N/A",N8-$M$1)
9	=IF(B9=1,$M$1,"N/A")	=IF(B9=1,$M$1+L9,"N/A")	=IF(N9="N/A","N/A",N9-$M$1)
10	=IF(B10=1,$M$1,"N/A")	=IF(B10=1,$M$1+L10,"N/A")	=IF(N10="N/A","N/A",N10-$M$1)
11	=IF(B11=1,$M$1,"N/A")	=IF(B11=1,$M$1+L11,"N/A")	=IF(N11="N/A","N/A",N11-$M$1)
12	=IF(B12=1,$M$1,"N/A")	=IF(B12=1,$M$1+L12,"N/A")	=IF(N12="N/A","N/A",N12-$M$1)
13	=IF(B13=1,$M$1,"N/A")	=IF(B13=1,$M$1+L13,"N/A")	=IF(N13="N/A","N/A",N13-$M$1)
14	=IF(B14=1,$M$1,"N/A")	=IF(B14=1,$M$1+L14,"N/A")	=IF(N14="N/A","N/A",N14-$M$1)
15	=IF(B15=1,$M$1,"N/A")	=IF(B15=1,$M$1+L15,"N/A")	=IF(N15="N/A","N/A",N15-$M$1)
16	=IF(B16=1,$M$1,"N/A")	=IF(B16=1,$M$1+L16,"N/A")	=IF(N16="N/A","N/A",N16-$M$1)
17	=IF(B17=1,$M$1,"N/A")	=IF(B17=1,$M$1+L17,"N/A")	=IF(N17="N/A","N/A",N17-$M$1)
18	=IF(B18=1,$M$1,"N/A")	=IF(B18=1,$M$1+L18,"N/A")	=IF(N18="N/A","N/A",N18-$M$1)
19	=IF(B19=1,$M$1,"N/A")	=IF(B19=1,$M$1+L19,"N/A")	=IF(N19="N/A","N/A",N19-$M$1)
20	=IF(B20=1,$M$1,"N/A")	=IF(B20=1,$M$1+L20,"N/A")	=IF(N20="N/A","N/A",N20-$M$1)
21	=IF(B21=1,$M$1,"N/A")	=IF(B21=1,$M$1+L21,"N/A")	=IF(N21="N/A","N/A",N21-$M$1)
22	=IF(B22=1,$M$1,"N/A")	=IF(B22=1,$M$1+L22,"N/A")	=IF(N22="N/A","N/A",N22-$M$1)
23	=IF(B23=1,$M$1,"N/A")	=IF(B23=1,$M$1+L23,"N/A")	=IF(N23="N/A","N/A",N23-$M$1)
24	=IF(B24=1,$M$1,"N/A")	=IF(B24=1,$M$1+L24,"N/A")	=IF(N24="N/A","N/A",N24-$M$1)
25	=IF(B25=1,$M$1,"N/A")	=IF(B25=1,$M$1+L25,"N/A")	=IF(N25="N/A","N/A",N25-$M$1)
26	=IF(B26=1,$M$1,"N/A")	=IF(B26=1,$M$1+L26,"N/A")	=IF(N26="N/A","N/A",N26-$M$1)
27	=IF(B27=1,$M$1,"N/A")	=IF(B27=1,$M$1+L27,"N/A")	=IF(N27="N/A","N/A",N27-$M$1)
28			
29			
30			
31			
32			

	A	B	C	D	E
33					
34	Scen #			Resource Req'mts	
35		Xij	Yij	M1	M2
36					
37	Res. Used:	=SUM(B3:B27)		=SUMPRODUCT(D3:D27,B3:B27)	=SUMPRODUCT(E3:E27,B3:B27)
38	*Available:*	*5*		*14*	*14*
39	Slack:			0	0
40	Totals:			=$D$37+$D$39	=$E$37+$F$40
41	*Precedence Relationships:*				
42	*1) X1 before X2*			=$B$3+$B$4	
43	*2) X2 before X4*			=$B$4+$B$6	
44	*3) X9 before X21*			=$B$11+$B$23	
45	*4) X15 before X16*			=$B$17+$B$18	
46	*5) X17 before X12*			=$B$19+$B$14	
47	*6) X18 = X19 = X20*				
48	*7) all platoons before comp*			= SUM ($C$3:$C$11) + $C$14 + SU	($C$18:$C$26))/19
49	(a) all PLTs before X10			(d) all PLTs before X14	
50	(b) all PLTs before X11			(e) all PLTs before X24	
51	(c) all PLTs before X13			(f) all PLTs before X25	

	F	G	H
33			
34			
35	DI	HV	WS
36			
37	=SUMPRODUCT(F3:F27,B3:B27)	=SUMPRODUCT(G3:G27,B3:B27)	=SUMPRODUCT(B3:B27,H3:H27)
38	*5*	*5*	*10*
39	0	0	0
40	=$F$37+$F$39	=$G$37+$G$39	=$H$37+$H$39
41			
42			
43			
44			
45			
46			
47			
48			
49			
50			
51			

	I	J	K	L
33				
34				
35	AR	PC	FV	Scenario Duration
36				
37	=SUMPRODUCT(B3:B27,I3:I27)	=SUMPRODUCT(B3:B27,J3:J27)	=SUMPRODUCT(B3:B27,K3:K27)	
38	5	5	5	
39	0	0	0	=SUM($D$39:$K$39)
40	=$I$37+$I$39	=$J$37+$J$39	=$K$37+$K$39	
41				
42				
43				
44				
45				
46				
47				
48				
49				
50				
51				

	M	N	O
33			
34			
35	Start	End	Time Remaining
36			
37			
38			
39	<==OBJ. FCTN:		
40			
41			
42			
43			
44			
45			
46			
47			
48			
49			
50			
51			

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